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APPLICATION OF NANO ALUMINUM IN MODIFIED EDM: PMEDM

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ABSTRACT

This research was conducted to investigate the effect of nano aluminum mixed with electrical discharge machining dielectric on surface roughness (Ra), corrosion rate and material removal rate (MRR) of titanium alloy. Conventional machining of titanium alloy is a challenge even when using non-conventional machining processes such as electrical discharge machining (EDM). Among the limitations of EDM are machined surface alteration, induced corrosion, low material removal rate and residual stress during the EDM process. A newly developed and improved EDM process known as powder mixed electrical discharge machining (PMEDM) is envisaged able to address some of the above mentioned problems. In this study, PMEDM machining performance on titanium alloy workpiece using nano aluminum powder is assessed to investigate its improvement for biomedical application. Machining process parameters such as peak-current, ON-time, gap voltage and nano aluminum concentration are varied when machining biomedical grade titanium alloy. PMEDM although still is its infancy has shown slight improvement in Ra, corrosion rate and material removal rate. MRR is improved about more than 33.33% due to effect of nano aluminum concentration.

Keywords: EDM, titanium alloy, implants, Ra, corrosion rate.

INTRODUCTION

The development of devices such as implants in biomedical engineering application nowadays requires hard alloy materials with good mechanical and physical properties. Titanium alloy is still the most widely used high tensile strength metal alloy as implants in biomedical engineering due to their excellent biocompatibility, good mechanical characteristic and corrosion resistance even though there are other new emerging materials suitable for biomedical applications [1]. Existing processes of machining implants for biomedical application includes turning, milling, drilling, forming, forging and alternative machining such as laser and water-jet cutting [2]. The limitations of these processes are the after machining effect on biocompatibility corrosion and residual stress induced during the machining process. Electrical discharge machining (EDM) is a non-conventional machining process that removes material by spark erosion generated from electrical discharges is suitable to machine "difficult to machine material". The drawback of EDM is its slow machining process with low MRR when machining high strength materials and some cases with relative rougher surface [3]. To overcome the above EDM limitations, use of metallic powder mixed with EDM dielectric is hypothesized to provide a potential solution. In PMEDM, metallic powder is added to dielectric fluid and it fills up the gap between the workpiece and the electrode as shown in Figure-1. Added metallic powder enhanced the sparks which becomes enlarged. Metallic powder particles under machining workpiece and electrode area get energized due to applied voltage. The energy of the conductive particle promotes the breakdown of dielectric fluid and increases the gap with between the workpiece and the electrode. Hence, early discharges start under the electrode area and create fast sparks which erodes the workpiece.

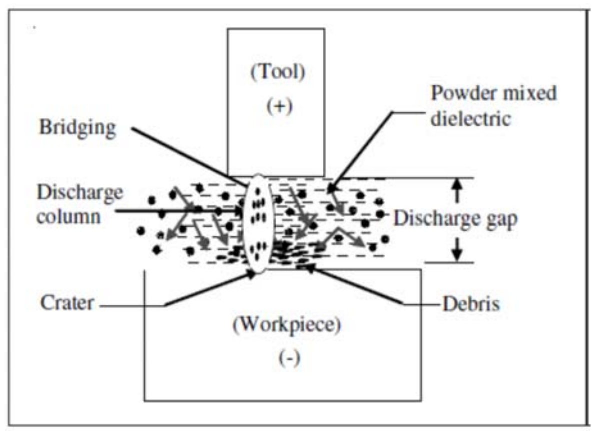

Figure-1. Schematic of PMEDM [4].

The spark is dispersed between the metallic powder and the discharge density decreases leading to the reduction of crack, craters and voids on the workpiece machined surface [5]. PMEDM can possibly further enhanced surface roughness and induced acceptable corrosion rate for improvement of implants machined surface properties. Hence, the objective of this research study is to evaluate the machined surface quality and corrosion rate in PMEDM.

MATERIALS AND METHODS

Experiments were conducted on EDM process to machine molybdenum high steel using copper-tungsten material as electrode with square cross-section of 9 mm x 9 mm. The workpiece is rectangular shape of 11mm x 9 mm x 5 mm with depth of cut at 3 mm. An operating tank with base conical shape was designed and fabricated for use of nano aluminum. A circulation and filtering system attached to operating tank for circulation of nano aluminum mixed with dielectric and side flushing of

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dielectric was implemented. Surface roughness, surface morphology and surface sensitivity were selected as output measures to evaluate the performance of PMEDM on machining titanium alloy as biomaterial. The EDM process parameters are listed are peak current, ON-tine and nano aluminum concentration. Equation 1 was used to determine material removal rate where MRR is in grams per minutes as the ratio of the difference of the mass in grams of the workpiece before and after machining to the machining time in minutes. The machining parameters are presented in Table-1.

$$MRR = \frac{Mass\,loss\,of\;\,workpiece}{machining\;time} \tag{1}$$

Table-1. Selected EDM machining parameters.

Process parameters	*Units*	*Symbol*	*Range of parameters*
Peak Current	[A]	Ip	27 - 51
Gap Voltage	[V]	GV	80 - 150
ON-Time	[µs]	ON	64 - 128
OFF-time	[µs]	OFF	128
Nano aluminum size	nm	40	
Nano aluminum concentration	[g/l]	Pcon	1 – 3
Workpiece	Ti-6Al-4V		

Surface roughness, corrosion rate and material removal rate were selected as output measurements to evaluate the performance of PMEDM on machining titanium alloy as biomaterial. The test and analysis was done on the samples in vitro. Surface roughness tester was used to measure the roughness of machined surface and the LPR method was used to analyze and determine the average corrosion rate.

Figure-2 presents the schematics of the PMEDM test-rig designed. Unique design as compared to all other existing PMEDM systems is the conical shape. The conical shape is designed to avoid the nano aluminum and debris to settle down at the corner of the operating tank. The critical dimension of the small tank is its height which must be more than the operating level of the dielectric fluid in the main tank.

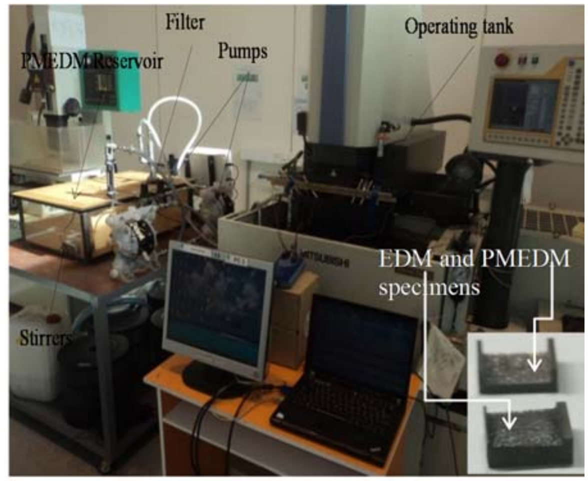

Figure-2. PMEDM test-rig.

RESULTS AND DISCUSSIONS

Surface roughness

Figure-3 presents the main effect plot of IP, ON-time and gap voltage of Ra machining titanium alloy. Ra is getting rougher when IP and ON-time vary from low to high setting value. Ra slightly increases with variation of gap voltage from 80 to 110V but it remains constant from 110 to 150V. The increase in Ra when IP varies from low to high set values can happened due to an increase in peak current which produces intense spark leading to rise in temperature heating electrode and workpiece zone causing rougher surface.

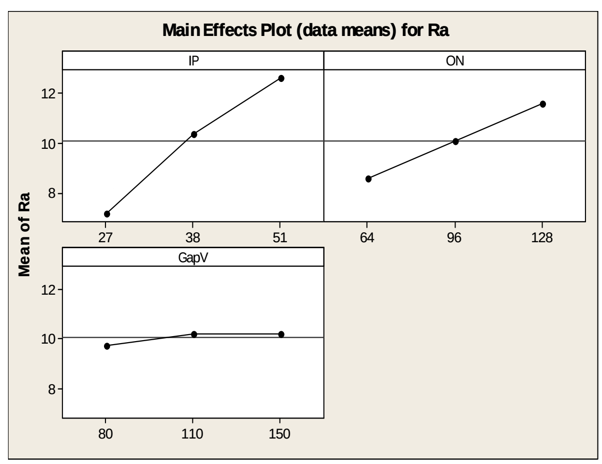

Figure-3. Surface roughness of EDM on titanium alloy.

Figure-4 presents the main effect plot of PMEDM on Ra when machining titanium alloy. Ra is smoother at low IP, but the effect of IP on Ra is pronounced when IP varies from 27 to 51Amp. Ra is improved for ON-time, gap voltage and nano aluminum concentration machining parameters. Surface roughness improvement using PMEDM is attributed to the discharge current which is uniformly distributed and discharged energy is reduced

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from the spark. This reduction of discharge energy lowers the surface roughness.

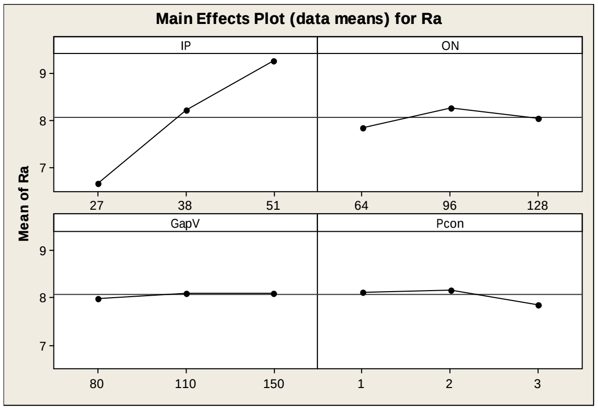

Figure-4. Surface roughness of nano aluminum PMEDM on titanium alloy.

It can be observed from Figure-4 that there is pronounced surface roughness improvement using PMEDM approach. This is attributed to increase in discharge gap due to nano aluminum in dielectric during electro-discharge in PMEDM process. The discharge current is uniformly distributed and discharged energy is reduced from the spark. This reduction of discharge energy lowers the surface roughness. Figure-5 shows the surface morphology of EDM on titanium alloy and Figure 6 the surface morphology of PMEDM on titanium alloy machined at the same peak current, ON-time and Gap voltage except the nano aluminum added in case of PMEDM. From Figure-5, the surface morphology indicates more rough on machined surface. Craters, voids and micro-cracks are more pronounced on surface machined at the set of Ip, ON-time and Gap voltage as. Non-uniform agglomerates distribution on the surface as it can be seen from Figure-5 contributing to rough machined surface. This is due high electrical discharge energy released on the surface during electro-discharge spark erosion since Peak current, ON-time and Gap voltage control the discharge energy [6]. Hasçalık and Çaydaş [7] stated similar effect of conventional EDM on titanium alloy using graphite electrode.

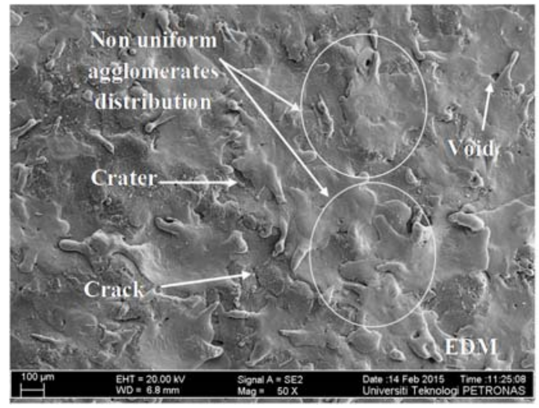

Figure-5. Morphology of EDM on machined surface of titanium alloy, machined with Ip-38 A and ON-96 µs, GV-110 V.

The surface morphology of PMEDM of titanium in Figure-6 shows an improvement of machined surface. The PMEDM surface morphology shows less rough surface. Craters, voids, and micro-cracks are reduced contrary to conventional EDM of titanium alloy.

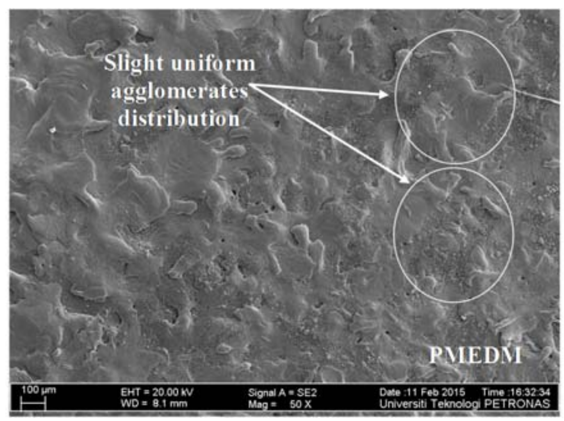

Figure-6. Morphology of nano aluminum PMEDM on machined surface of titanium alloy machined with Ip-38 A and ON-96 µs, GV-110 V, Pcon-3 g/l.

The addition of nano aluminum can reduce the electrical discharge power resulting in smaller craters, cracks on machined surface. PMEDM of titanium alloy presents advantage of improving machined surface.

Corrosion rate

The Ti-6Al-4V specimens as received and machined using EDM and PMEDM processes were immersed in Hank´s solution, the body fluid. The results of 3 hours' linear polarization with 6 reading points are presented in Figure-7. The improvement of the PMEDM corrosion rate is due to improvement of machined surface irregularities and microstructure by nano aluminum mixed with dielectric fluid. The electrochemical corrosion results show that corrosion resistance of the specimens which are machined by PMEDM is about two times more than the specimens which are machined using PMEDM.

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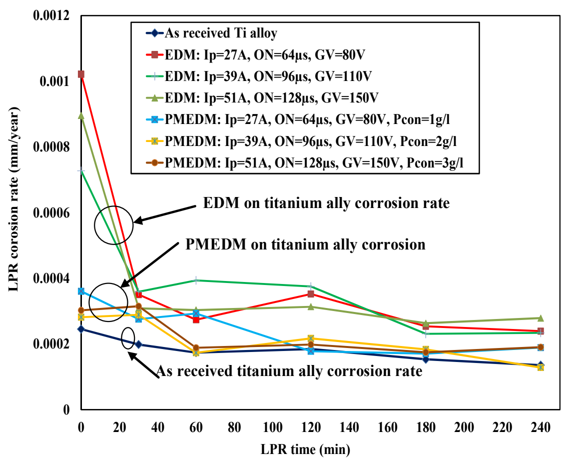

Figure-7. LPR corrosion rate of EDM and PMEDM of titanium alloy.

Corrosion is induced during the EDM of titanium alloy but corrosion rate is reduced with PMEDM and slightly closed to as received titanium alloy. The average corrosion rate of PMEDM of 2.28266 10^{-4} mm/year of titanium alloy is closed to the accepted corrosion rate for metallic implants which is about 2.5 x 10^{-4} mm/y [8] compared to the average corrosion rate of EDM of 3.98554 10^{-4} mm/year.

Material removal rate

The effect of IP, ON-time and gap voltage on MRR is presented in Figure-8.

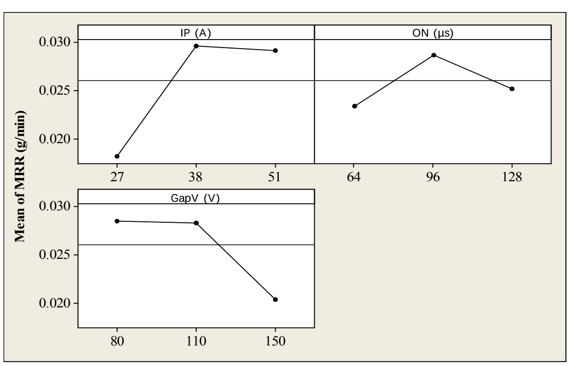

Figure-8. Effects plot for MRR of EDM on titanium alloy.

MRR is increasing with the variation of IP and ON-time from low to center point values and it decreases from the center point to high values. Figure 9 presents the main effect of IP, ON-time, gap voltage and nano aluminum concentration on MRR. More materials are removed from the workpiece with variation of IP, ON-time and nano aluminum concentration. The improvement of MRR is due to accumulation of sparks between two consecutive nano aluminum particles in machining area results in series of discharge which increases the spark intensity leading to faster removal of material from the workpiece and therefore increases MRR.

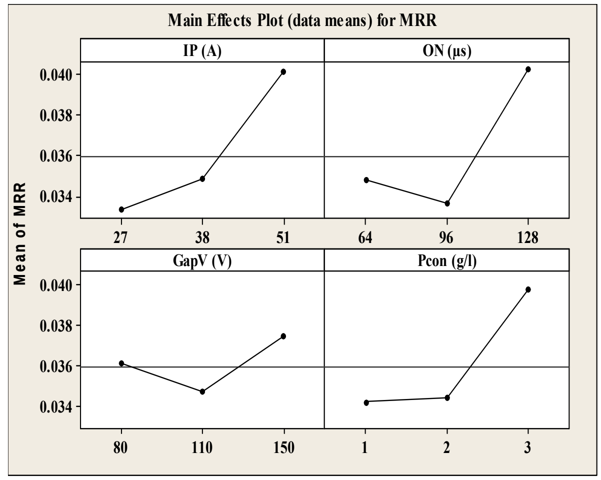

Figure-9. Effects plot for MRR of nano aluminum PMEDM on titanium alloy.

The increase of MRR through PMEDM is due to increase and uniform distribution in spark discharge energy contributing to increase of the MRR. With nano aluminum mixed-dielectric MRR is improved about more than 33.33% due to effect of nano aluminum concentration. Peak current, ON-time, gap voltage and nano aluminum concentration have impact on material removal rate but effect of peak current is more pronounced. Soumyakant *et al* [9] showed similar effect of metallic powder when machined EN 31 steel that MRR tends to increase significantly with increase in peak current. Peak current, voltage, ON-time have dominant control over electrical discharge energy [6].

CONCLUSIONS

PMEDM improves the surface roughness of the machined titanium alloy. This is attributed due to transfer of alloying elements deposited from nano aluminum onto the machined surface. The corrosion is reduced trough PMEDM of titanium alloy and is slightly closer to the as received titanium alloy which is in acceptable corrosion rate for metallic implant required. PMEDM shows promising results and can be explored for various applications including industry, biomedical. More material is achieved with PMEDM. MRR is improved about more than 33.33% due to effect of nano aluminum concentration. The increase of MRR through PMEDM is due to the increase and uniform distribution in spark discharge energy contributing to increase of the MRR.

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