euspen's 18th International Conference & Exhibition, Venice, IT, June 2018
www.euspen.eu

Investigating the potential of electrical discharge machining for antibacterial coating of titanium implants

Viet D. Bui[1*], James W. Mwangi [1], Thomas Berger[1], Andreas Schubert[1,2]

[1] *Technische Universität Chemnitz, Professorship Micromanufacturing Technology, Reichenhainer Strasse 70, 09126 Chemnitz, Germany*
[2] *Fraunhofer Institute for Machine Tools and Forming Technology, Reichenhainer Strasse 88, 09126 Chemnitz, Germany*

** Corresponding author. Tel.: +49-371-539-71943; fax: +49-371-539-761943. Email address: viet.bui-duc@s2016.tu-chemnitz.de*

Abstract
Titanium and titanium alloys are some of the best materials for medical implants owing to their excellent properties including biocompatibility, corrosion resistance and high fatigue strength among others. However, many implants have to be removed after implantation because of bacterial infection. Coating titanium implants with copper or silver has demonstrated antibacterial abilities and has therefore been widely applied to solve this problem. Ion implantation, physical vapour deposition, magnetron sputtering and many other different methods are used to coat these materials. However, until now, there is no method that allows for concurrent machining and coating of the antibacterial layer.
Electrical Discharge Machining (EDM) has demonstrated its potential on surface modification owing to the fact that the material from tool electrode and/or powder mixed in dielectric fluid is implanted on the workpiece thereby changing its characteristics. In this study, the suitability of EDM for coating copper and silver on titanium alloy is investigated. Titanium alloy samples are machined using a high precision EDM machine and later analysed for surface quality and chemical composition.

Titanium, EDM, antibacterial, chemical composition, surface layer

1. Introduction

Titanium and its alloys are widely used in many biomedical implant applications. However, a complex issue of these implants is the formation of biofilms on titanium surface after implantation. Coating an antibacterial layer on titanium implants is a solution for this problem [1]. The inorganic materials used for this coating layer are copper, silver, etc. Several coating methods such as ion implantation, physical vapour deposition, magnetron sputtering and other methods are used. These methods require additional processes to deposit the antibacterial layer.

Table 1. Effect of silver (Ag) and copper (Cu) element on the antibacterial effect (AE) of various ion implanted materials [2].

Samples	Ag ion implantation		Cu ion implantation	
	Ag content (wt.%)	AE (%)	Cu content (wt.%)	AE (%)
Pure Ti	0	0	0	0
	0,68	83	0,92	31
	0,96	99,9	1,69	49
	1,21	100	3,05	90
	1,22	100	4,70	100
Ti-Al-Nb	0	0	0	0
	0,72	67	1,34	28
	1,02	99	1,85	42
	1,32	100	3,39	80
	1,52	100	4,84	99,9

Ti-Cu alloy is an antibacterial material with a high potential for application as an implant material because of its strong antibacterial activity and good cell biocompatibility [3]. Compared to copper, silver is more biocompatible. The antibacterial performance of copper and silver coated on pure titanium and Ti-Al-Nb was investigated using ion implantation method [2]. The result showed that silver ion implantation has a stronger antibacterial property than copper ion implantation [Table 1].

Electrical discharge machining is a method widely used in machining titanium implants. It has also shown its potential in coating material from tool electrode or powder suspended in dielectric fluid on workpiece surface [4]. Additionally, dielectric fluid and tool electrode play an important role on surface roughness and chemical composition of EDMed surface [5]. In this study, a method that allows for concurrent machining and coating copper and silver on titanium implants is investigated.

2. Methodology

This study utilised a (10 × 10 × 1) mm^3 Ti-6Al-4V workpiece whose chemical composition is as presented in Table 2. In order to investigate the migration of tool electrode material to the workpiece surface, a 5 mm copper tool electrode was used in the electrical discharge milling process, using oil and deionized water as the dielectric fluids and applying four discharge energy levels as shown in Table 3.

Further experiments were carried out at low discharge energy (9.98 µJ) to evaluate the possibility of implanting powder material on EDMed surface.

Silver nano-particles (99,9 % purity and 50-60 nm size) were mixed with oil dielectric fluid in different concentrations. Each dielectric fluid concentration was used to machine three samples using a 5mm Ti-6Al-4V tool electrode.

After machining the samples were cleaned in an ultrasonic bath containing ethanol and later dried. A 3D-Laserscanning-Confocal-Microscope Keyence VK-9700 was used to measure the surface roughness of each sample from 3 machining repetitions. For each measurement, a 0.5 mm x 4 mm area was observed at a 50X magnification. Ra and Rz were analyzed by the Software MountainsMap 7.4 using a cut-off value of 0.25 mm. Surface composition of the workpiece was examined with the use of energy dispersive X- Ray Spectroscopy (EDS).

Table 2. Ti-6Al-4V chemical composition

Element	Al	Ti	V
wt. %	6,03	89,79	4,18

Table 3. Actual discharge energies for different Sarix T1-T4 CF settings

Voltage u_0: 160 V				
CF	0	2	4	6
We [μJ]	9,96	43,38	92,23	124,39

3. Results and Analysis

3.1. Surface quality analysis

The influence of discharge energy and dielectric fluid on surface roughness of Ti-6Al-4V is as shown in Figure 1. It can be revealed that surface roughness increases at higher pulse energy because of the bigger and deeper craters. Besides, at high pulse energy, deionized water has demonstrated an ability to provide a lower surface roughness than oil dielectric. However, the opposite occurs at low discharge energy whereby oil provided a lower roughness after EDM.

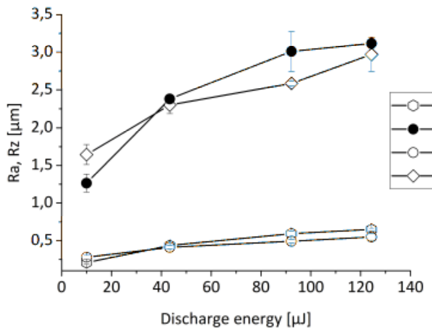

Figure 1. Influence of discharge energy and dielectric fluid on surface roughness of Ti-6Al-4V

As shown in Figure 2, EDMed surface roughness of Ti-6Al-4V using nano-silver powder mixed dielectric fluid is higher than pure dielectric. It also has a slight increase at higher powder concentration.

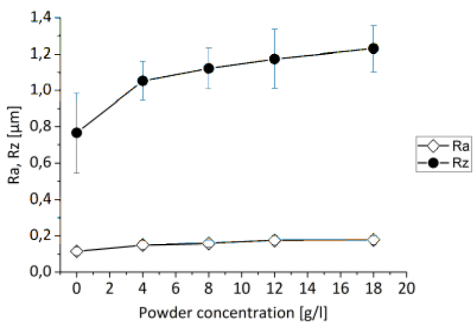

Figure 2. Surface roughness of Ti-6Al-4V in electrical discharge sinking at different powder concentration

3.2. Surface compositional analysis

As shown in Figure 3, material from copper tool electrode was implanted on the EDMed surface of titanium alloy. Additionally, this copper content was strongly affected by discharge energy and dielectric material. Titanium alloy surfaces machined using deionized water contained more copper than their oil machined counterparts. Simultaneously, the percentage of copper increases with increasing discharge energy at high pulse energy. However, for low discharge energy, there seems to be a trend whereby an increase in discharge energy results in a decrease in the percentage of copper deposited on the machined surface.

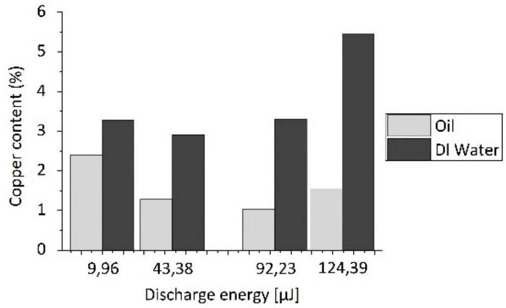

Figure 3. Copper content of the surface layer at different discharge energy for oil and water dielectric

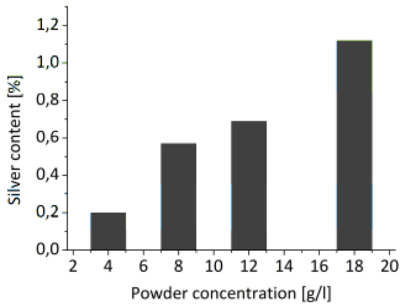

Figure 4. Silver content of the surface layer at different powder concentration in oil dielectric

Figure 4 shows that the material from the silver powder is implanted on the EDMed surface and powder concentration has a strong effect on this migration. It also indicates that the percentage of silver content migrating from powder to titanium surface was enhanced by increasing powder concentration.

4. Conclusions

The following conclusions can be drawn from this research:

- The implantation of materials from tool electrode and powder mixed dielectric on EDMed surface can be controlled by pulse energy, dielectric fluid material and powder concentration. Surface roughness is also affected by these parameters.
- EDM has a potential for concurrent machining and coating copper and/or silver on titanium implant surfaces.

References

[1] Zhao L, Chu P K, Y. Zhang and Wu Z, "Antibacterial coatings on titanium implants", in *J. Biomed. Mater. Res. B Appl. Biomater.*, vol. **91 (1)**, (2009), pp. 470-480

[2] Wan Y Z, Raman S, He F and Huang Y, "Surface modification of medical metals by ion implantation of silver and copper", in *Vacuum*, vol. **81 (9)**, (2007), pp. 1114-1118

[3] Liu J, Zhang X, Wang H, Li F, Li M, Yang K and Zhang E, "The antibacterial properties and biocompatibility of a Ti-Cu sintered alloy for biomedical application", in *Biomed. Mater.*, vol. **9 (2)**: 025013, (2014), doi: 10.1088/1748-6041/9/2/025013

[4] Murray J W and Clare A T, "Morphology and wear behaviour of single and multi-layer electrical discharge coatings", in *Procedia CIRP 42*, (2016), pp. 236-239

[5] Mwangi J W, Zeidler H, Berger T, Schubert A, "Influence of dielectric fluid and tool electrode choice on micro-EDMed nitinol surface integrity", in *Proc. euspen's 17th International Conference & Exhibition,* (2017).