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A comparative study on micro-electro-discharge-machined surface characteristics of Ni-Ti and Ti-6Al-4V with respect to biocompatibility

Muhammad P. Jahan[a,*], Pegah Kakavand[b], Farshid Alavi[b]

[a]Department of Mechanical and Manufacturing Engineering, Miami University, Oxford, OH 45056, USA
[b]Department of Architectural and Manufacturing Sciences, Western Kentucky University, Bowling Green, KY 42101, USA

Abstract

Ti-6Al-4V (grade 5 titanium alloy) and NiTi (shape memory alloy) are two commonly used materials for biomedical orthopedic and orthodontic applications. The surface characteristics of the biomedical implants play a significant role on the biocompatibility and mechanical strength of the implants. The objective of this study is to investigate and compare the surface characteristics of NiTi shape memory alloy (SMA) and Ti-6Al-4V alloy after machined using micro-electro-discharge machining (micro-EDM). The machined surfaces were analyzed for topography, composition, migration of materials and microhardness. The results showed that NiTi SMA produced comparatively smoother surface finish. The analysis of elemental composition indicated migration of materials to the workpiece from the dielectric and the tool electrode. There is formation of TiO_2 and $NiTiO_3$ layers on the machined surfaces of Ti-6Al-4V and NiTi respectively. The surface microhardness increased in both NiTi and Ti-6Al-4V workpieces after micro-EDM due to the formation of the oxide layers. The formation of oxide layers can be beneficial for both materials when used as biomedical implants, as commercial implants contain protective oxide coatings to minimize the corrosion inside human body.

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Keywords: Ti-6Al-4V; NiTi; surface topography; microhardness; biocompatibility.

* Corresponding author. Tel.: +1-513-529-0347; fax: +1-513-529-0717.
E-mail address: jahanmp@miamiOH.edu

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1. Introduction

Ti-6Al-4V and NiTi are two widely used materials for biomedical applications due to their excellent mechanical properties and outstanding corrosion resistance [1, 2]. The conventional machining processes are found to be cost ineffective for machining these materials because of their specific properties such as high strength, high resistance to wear, lower thermal conductivity, strong alloying tendency, and reactivity to the cutting tools [3, 4]. Electrical Discharge Machining (EDM) is one of the most widely used non-conventional machining processes for machining such difficult-to-cut materials [5, 6]. There have been numerous studies on the conventional EDM of NiTi and Ti-6Al-4V alloys, which will be discussed in the following two paragraphs.

Lin et al. [7] investigated the electro-discharge machining characteristics of NiTi SMA by varying operating parameters and studying their effect on EDM performance. It was found that a longer pulse duration and a lower peak current provided improved machining performance. It was also found that both material removal rate (MRR) and electrode/tool wear ratio (EWR/TWR) increased with the increase of peak current. Alidoosti et al. [8] investigated the machining characteristics of NiTi SMA based on full factorial design. They varied the pulse current and pulse interval, and used two different electrode materials – copper tungsten (CuW) and copper (Cu) – to investigate the effect of operating parameters on EDM performance. It was reported that there was no significant difference in the machining performance of CuW and Cu electrodes for EDM of NiTi SMA. However, with the increase of pulse current, the MRR, EWR and surface roughness (SR) increased due to the increase of discharge energy. Chen et al. [9] investigated the EDM machinability of two NiTi based SMAs, i.e. $Ti_{50}Ni_{49.5}Cr_{0.5}$ and $Ti_{35.5}Ni_{49.5}Zr_{15}$. It was reported that the MRR of NiTiX alloys exhibited reverse relationship to the products of respective alloy's melting point and thermal conductivity. It was also reported that the SR after the EDM process showed a co-relationship with the product of pulse duration and pulse interval. Huang et al. [10] investigated the machinability of $Ni_{50.6}Ti_{49.4}$ alloy for wire-EDM and laser machining processes. It was reported that laser machining using an ultra-short pulse laser provided lower SR and heat affected zone (HAZ) in the NiTi SMA compared to those generated during the wire EDM. Daneshmand et al. [11] compared the EDM machinability of NiTi SMA without and with tool rotation. They investigated the effect of pulse current, gap voltage, pulse duration and pulse interval on the MRR, SR and TWR for traditional and rotational EDM. It was found that irrespective of tool rotational speed the operating parameters have similar effect on the machining performance, although the tool rotational speed of 200 RPM led to lesser MRR and reduced SR and TWR. It was also found that for all settings of voltage, the rotational EDM provided lower MRR, TWR and SR than stationary EDM. Sabouni and Daneshmand [12] studied the effect of EDM process parameters during machining of NiTi SMA with graphite electrodes using Taguchi's method and proposed optimized process parameters for improved machining performance. Besides parametric studies, there have been several studies on the surface characteristics and properties changes of NiTi SMA after EDM. Hsieh et al. [13] investigated the surface characteristics and shape recovery ability of $Ti_{35.5}Ni_{48.5}Zr_{16}$ and $Ni_{60}Al_{24.5}Fe_{15.5}$ ternary SMAs after the EDM process. They found the similarity in the surface characteristics between the two SMAs and reported that the machined surface was composed of craters, recast layer of molten metals and micro-cracks. They also found that the thickness of recast layer increased with the increase of pulse duration for both materials. In addition, the discharge crater sizes also increased with the increase of pulse duration and pulse discharge energy. However, in their study they reported a critical depth of recast layer after which there was sudden decrease in hardness of the machined surface. Liu et al. [14] investigated the differences in surface characteristics for one single main cut and multiple trim finish cut during the wire-EDM of NiTi SMA. It was found that the single main cut generated higher thickness of recast layer (2 – 8 μm) with various surface defects and micro cracks. On the other hand, the finish cut was found to reduce the recast layer thickness significantly (0 – 2 μm) in addition to reducing the surface defect. They reported slight increment in the microhardness at higher depths from the machined surface for both main cut and trim cuts. Besides studies on conventional EDM, there have been few studies on the micro-EDM of NiTi SMAs. Rasheed et al. [15] investigated the effect of operating parameters on the MRR, TWR and SR during the micro-EDM of NiTi SMA. It was reported that the MRR and SR were greatly influenced by discharge voltage, capacitance and electrode materials. The TWR and SR were found to be lower at lower discharge energy. The tungsten electrode was recommended for higher MRR and brass electrode was recommended for lower SR. Huang et al. [16] investigated the effectiveness of ultrasonic vibration in enhancing the flushing condition and overall machining performance during the micro-EDM of NiTi SMA. It was reported that the introduction of ultrasonic vibration increased the machining efficiency by 60 times, without increasing the electrode wear significantly.