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Suitability assessment of micro-EDM in machining Nitinol for medical applications

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Abstract

Among the latest developments in the medical field is the shift from open surgical procedures requiring long healing times to minimally invasive ones. These can lead to drastically reduced recovery times and even be done at out-patient facilities. In the centre of this development is Nitinol, a material which due to shape memory effect, pseudoelasticity and other unique properties, has found numerous applications including in making stents, arcwires and endoscopic instruments.

With miniaturization, the challenge to produce these parts feasibly while maintaining high accuracy standards increases. While it is possible to machine Nitinol using conventional manufacturing processes like turning and grinding, these processes are limited for micro- and high precision machining, especially for thin-walled and fragile parts. They generate a lot of tool wear and can also result in unwanted force induced stresses in the workpiece.

Micro electrical discharge machining (micro-EDM), a non-contact thermal ablation process which uses electrical discharges to machine the workpiece, can be used to address these challenges as it can realise miniature parts irrespective of their hardness or brittleness. In this paper, the suitability of micro-EDM in machining Nitinol for medical applications is investigated by comparing it to Steel and Tungsten Carbide (WC). Samples are machined using SARIX SX-100 high precision machine and analysis is done with regards to the process quality and dimensional accuracy. The results show that Nitinol is machinable by micro-EDM. However, the process is generally the slowest of the three materials and TWR is high.

Keywords: Nitinol; micro-EDM, shape memory effect, pseudoelasticity

1. Introduction

Precision engineering has found an even greater meaning with rising demand for miniaturized products which require very tight tolerances. In medical applications, this is coupled with demands for materials which are biocompatible, wear resistant and have high fatigue strength. Materials like composites, ceramics and shape memory alloys have been developed to deal with this challenge, offering better and unique properties as compared to established materials like steel and aluminium. In hindsight however, this has introduced the challenge of machining them. Micro-EDM is suited to solve this challenge since it can machine intricate profiles on materials irrespective of their hardness as long as the minimum required electric conductivity is above $10^{-2}\Omega^{-1}$ cm^{-1} [1].

2. Unique properties of Nitinol

Nitinol has two special properties, superelasticity (mechanically induced) and shape memory effect (thermally induced). As shown in Fig. 1, Nitinol in an austenite state at origin point O is cooled along path OA with no applied stress and passes through transformation points A_f (Austenite finish), A_s (Austenite start), M_s (martensite start) and finally M_f (martensite finish) in a twinned state. Deformation through de-twinning and reorientation occurs from point A to B with elastic unloading from point B to C. The material stays deformed until a temperature induced transformation by heating to a temperature above A_f after which it recovers the pseudoplastic deformation ("remembers") returning to its original shape. Above A_f, the alloy can be loaded from point O to E through a stress induced martensitic transformation achieving strains as high as 11% [2]. As long as the point of permanent deformation is not reached, the material transforms back to the austenitic state recovering the superelastic deformation, hence the hysteresis loop seen in Fig. 1.

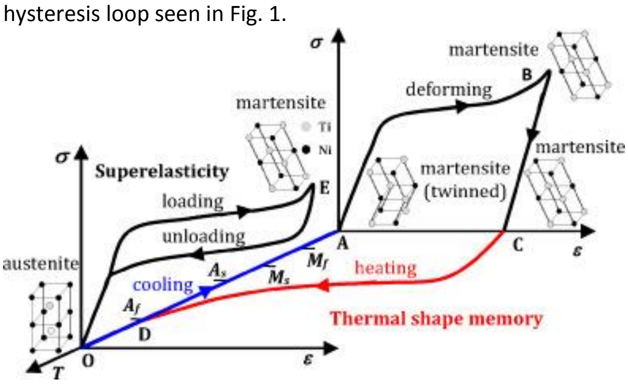

Figure 1. Stress-Strain-Temperature diagram for Nitinol [2].

3. Nitinol material selection justification

Rather than wire, heat treated Nitinol sheet was used for this research. Sheet has the capacity to liberate product design by offering increased design freedom and unique product attributes. It has also found increased applications like in making of super-elastic clips for orthodontic brackets and vascular closure devices, used to seal access sites following percutaneous catheter intervention. For tubes, the larger the diameter, the more expensive and labour intensive the process becomes opening up an advantage for using EDM, for example in making cardiac valves. The sheet is EDM-cut and then formed into a tubular component [3].

4. Methodology

Using a Sarix SX-100 HPM micro EDM machine, the experiments were set up as shown in Fig. 2. Bores with a target depth of 0.5 mm were machined on 3 different materials i.e. Nitinol, Steel and Tungsten Carbide (WC). This enabled a comparison and therefore better insight into the Nitinol machining process. HEDMA111 oil was used as the dielectric fluid and Tungsten Carbide (90µm diameter) as the tool electrode. The desired energy level, open circuit voltage u_0, load frequency $f = 150$ kHz and tool polarity (negative) were selected.

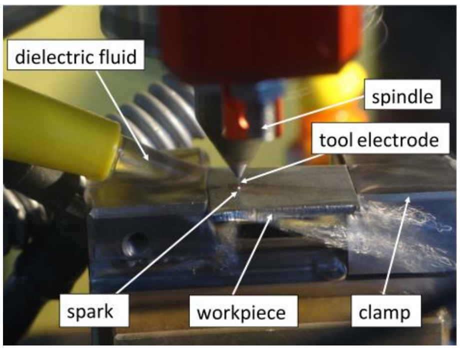

Figure 2. Experimental setup.

5. Results and Analysis

From the experiments, the following results were achieved:

5.1 Machinability

Body Temperature Nitinol (37°C) is machinable by micro-EDM. For the same machining conditions, the nature of the discharges realised from the three materials is remarkably similar as shown in Fig. 3. A voltage of $u_0 = 100$V and a discharge energy of 6.2µJ resulted in a mean pulse width of 179ns for both Nitinol and Steel, and 174ns for WC. Peak currents were 3.87A, 4.06A and 3.8A for Nitinol, Steel and WC respectively.

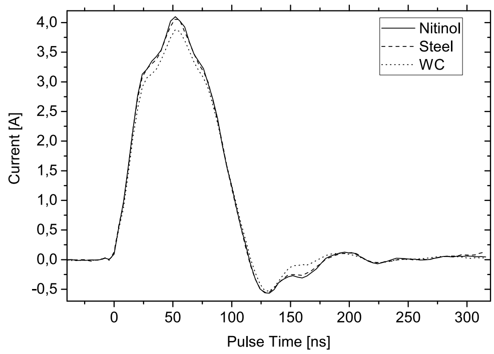

Figure 3. Mean pulses for u_o=100V and CF102 (6.2µJ)

5.2 Effect of voltage and discharge energy

As shown in Fig. 4 and Fig. 5, an increase in open circuit voltage and/or an increase in discharge energy results in an increase in both material removal rate (MRR) and tool wear rate (TWR) up to a certain value, after which there is a decrease. This decrease could be because higher machining power results in increased debris and after an optimum value, a further increase results in too much debris and/or poor flushing, thus resulting in more short circuits.

Nitinol's MRR was generally the lowest of the three materials and for higher voltage values, TWR is either almost equal to MRR or more, signifying a deterioration in the process.

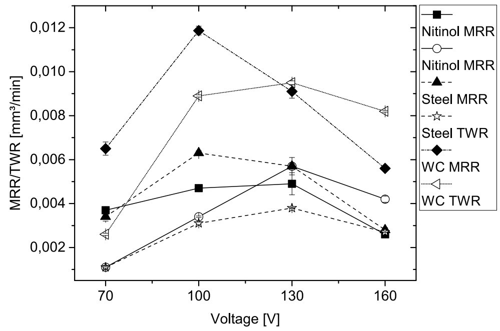

Figure 4. Effect of open circuit voltage on MRR and TWR for energy level 102.

Table 1: Effect of voltage on bore diameters

Material	Voltage (V)			
	70	100	130	160
Nitinol	112.2 ± 1.0	116.6 ± 0.6	121.7 ± 1.5	126.2 ± 0.9
Steel	112.8 ± 1.1	113.6 ± 0.4	119.7 ± 0.6	133.4 ± 2.3
Tungsten Carbide	112.8 ± 0.9	116.6 ± 0.9	119.9 ± 1.3	123.4 ± 1.4

Higher voltages and/or discharge energies not only resulted in larger bore diameters as shown in table 1 and table 2, but also produced bores with irregular edges.

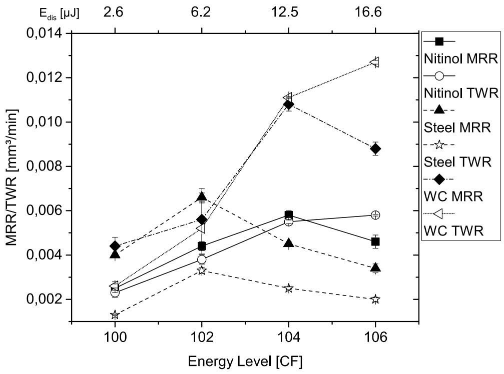

Figure 5. Effect of discharge energy on MRR and TWR for u_o=100V.

Table 2: Effect of Discharge Energy on bore diameters

Material	Discharge Energy (µJ)			
	2.6	6.2	12.5	16.6
Nitinol	114.7 ± 0.7	117.4 ± 0.8	121.8 ± 1.2	124.3 ± 1.1
Steel	111.5 ± 0.5	114.9 ± 0.5	120.0 ± 1.0	127.0 ± 1.4
Tungsten Carbide	111.5 ± 0.9	113.0 ± 1.6	118.9 ± 0.9	123.5 ± 1.3

6. Conclusions and recommendations

Even though it is possible to machine Body Temperature Nitinol using Micro-EDM, results indicate a low material removal rate and a high tool wear rate. Further studies are recommended to establish optimum machining conditions not only for machining micro bores, but also for micro-EDM milling.

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