Electrical Discharge Wire Cutting Performance of $Ni_{55.95}Ti_{44.05}$ Shape Memory Alloy

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Abstract

Shape memory alloys (SMAs) are widely used in many sectors like aerospace, biomedical, automobile due to its unique properties such as superelasticity/ pseudoelasticity, shape memory effect, high corrosion resistant, high specific strength, high wear resistance and many other enriched mechanical and physical properties. Machining of SMAs is a major concept in the field of SMAs applications. Nevertheless, the conventional machining of SMAs is extremely difficult. To overcome the difficulties during conventional machining, Electrical Discharge Wire Cutting (EDWC) can successfully utilize to machine SMAs. In EDWC, around 70% of the machining cost is associated with wire used in machining. The experimental study explores the effect of machining parameters of EDWC, namely, pulse on time (T_{ON}), pulse of time (T_{OFF}), spark gap voltage (SV), wire feed rate (WF) and wire tension (WT) on wire wear ratio, dimensional deviation and surface morphology of brass wire. Wire surface after machining is characterized by many debris, recast layer, micro-cracks & voids while examined through scanning electron microscope (SEM).

Keywords: SMA, WEDM, WWR, DD, SEM.

1. INTRODUCTION

In recent times, Ni-rich NiTi SMAs are gaining more significance compared to equiatomic and near equiatomic NiTi SMAs due to their excellent shape memory effect (SME), superelasticity/pseudoelasticity (SE) and many other enriched mechanical and physical properties [1]. Owing to high corrosion resistance, high strength and high work density, these SMAs are the most suitable candidate for biomedical, aerospace, robotics and automotive industries. However, conventional machining of these alloys is still an extremely challenging task. To surmount the obstacles during conventional machining of SMAs, various non-conventional machining approaches such as laser machining, electro chemical, water jet and electric discharge machining have been chosen by many researchers for the successful machining of SMAs [2, 3].EDWC, more commonly known as WEDM [4], is one of the versatile techniques to machine hard and conductive alloys and SMAs. Wire electric discharge machining (WEDM) process has high potential to machine these SMAs with high productivity and surface quality. WEDM, a special variant of EDM, is a sparks based advanced machining process which uses a continuously moving conductive wire as an electrode. In WEDM, material removal occurs as a result of spark erosion as the wire electrode is fed from a fresh wire spool through the workpiece [5, 6]. WEDM process is known for its accuracy and precision. In WEDM, around 70% of the machining cost is associated with wire used [7]. In WEDM, the study of wire wear phenomena is very necessary for economic machining.

The machining of SMAs is an extremely challenging task, many severe problems such as machine surface’s hardening, tool wear, large cutting time and poor surface quality are encountered by many researchers in conventional machining of SMAs [8, 9]. Hesish et al. [10] studied the machining characteristics of TiNiX(X=Zr/Cr) ternary SMAs in WEDM process and found that the product of the melting temperature and thermal conductivity of SMAs in WEDM strongly influenced the machining characteristic. Manjaiah et al. [11] conducted WEDM of equiatomic ($Ti_{50}Ni_{50}$) SMA and studied the effect of input variables (servo voltage, pulse duration, flushing pressure, pulse off time, & wire speed) on MRR& surface roughness. It was concluded that pulse on time had maximum contribution followed by pulse off time and flushing pressure for maximizing MRR and minimizing surface roughness. Kuamr et al. [12] studied the effect of machining parameters on cutting rate, surface roughness, dimensional deviation and wire wear ratio in WEDM and found that peak current, pulse on time, pulse off time and spark gap voltage strongly affected the response parameters. Sharma et al. [13] conducted WEDM of high strength low-alloy steel (HSLA) and investigated the effect of input parameters (pulse on time, pulse off time, spark gap voltage, peak current, and wire tension) on cutting speed and dimensional deviation. It was observed that for dimensional deviation, spark gap voltage and pulse on time were the most significant factors. Ghodsiyeh et al. [14]studied the effect of input parameters such asservo voltage, pulse duration, peak current, pulse off time on wire wear ratio, spark gap, wire lag and white layer thickness for titanium alloy (Ti6Al4V). Peak current was the most influencing parameters for wire wear ratio.

From the intensive scrutiny of literature, it is found that very handful work has been reported on the study of machining characteristics of Ni-rich NiTi SMAs in WEDM. However, the literature on the effects of input parameters on wire wear ratio and dimensional deviation in WEDM of SMAs is almost negligible. The aim of this investigation is to study the effect of machining parameters such as, pulse on time (T_{ON}) and pulse off time (T_{OFF}), spark gap voltage (SV), wire feed rate (WF) and wire tension (WT) on wire wear ratio (WWR) and dimensional deviation (DD) in WEDM of $Ni_{55.95}Ti_{44.05}$SMA using one factor at a time approach (OFAT). The wire surface after machining was examined through scanning electron microscope (SEM) image.

2. MATERIALS AND METHODOLOGY

2.1 Material

Ni-rich ($Ni_{55.95}Ti_{44.05}$ wt.%) SMA was chosen for this experimental investigation. $Ni_{55.95}Ti_{44.05}$SMA of dimensions 165 × 165 × 6 mm^3in a square plate form was selected. The elemental composition of SMA was detected by Energy dispersive X-ray spectrometry (EDS) analysis. The elemental composition of $Ni_{55.95}Ti_{44.05}$SMA using EDS analysis is shown in Fig. 1. The martensitic phase transformation temperatures

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(calculated by DSC test) and other properties of SMAs are given in Table 1.

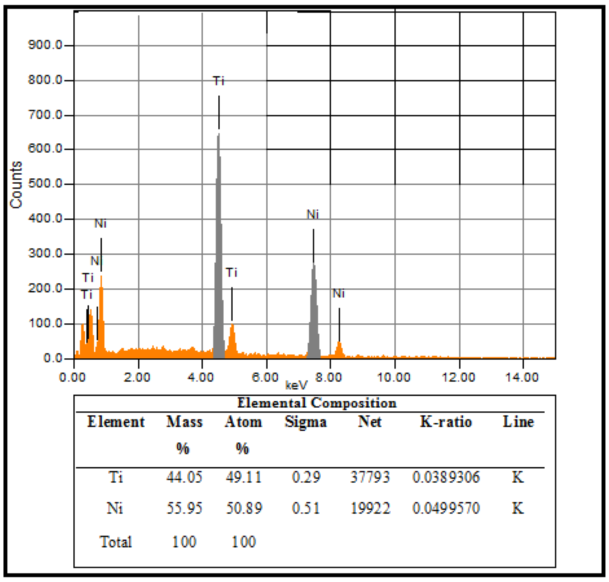


Fig.1. EDS analysis of $Ni_{55.95}Ti_{44.05}$ SMA

Table 1: Properties of $Ni_{55.95}Ti_{44.05}$ SMA

Property	Value
Density (g/cm^3)	6.7
Martensite start temperature (°C)	10.33
Martensite finish temperature (°C)	-14.50
Austenite start temperature (°C)	31.45
Austenite finish temperature (°C)	56.19
Hardness (Hv)	327

2.2 Experimental Procedure

Electronica Ultracut, 843 four-axis CNC wire electric discharge machine was utilized to cut the samples of size 10 × 10 × 6 mm^3 from the workpiece. The process parameters of WEDM namely, pulse on time (T_{ON}), pulse off time (T_{OFF}), spark gap voltage (SV), wire feed rate (WF) and wire tension (WT) were considered for experimental investigations. The effect of individual parameters on wire wear ratio (WWR) and dimensional deviation (DD) was analyzed using one factor at a time (OFAT) approach. The variable process parameters and their levels are given in Table 2. Flushing pressure (7 kg/cm^2), dielectric conductivity (±20-24µs/m), servo feed (2060) and peak current (12 A) were fixed during experimentation. WWR and DD were selected as a performance characteristic. Wire wear ratio (WWR) may define as the loss in weight of wire after WEDM which was calculated using equation (1) [12].

$$WWR = \frac{WWi - WWf}{WWi} \qquad (1)$$

Where, WW_f = Final weight of wire per unit length i.e. weight of wire after machining and WW_i = Initial weight of wire per unit length i.e. weight of wire before machining.

Dimensional deviation may define in terms of deviation of wire trajectory i.e. the difference between desired job profile and actual profile traced by wire. Mitutoyo digital micrometer was utilized to measure the DD having least count 0.001 mm. The DD was calculated using equation (2) [12].

$$\text{Dimensional Deviation (DD)} = 0.5 \text{ (width of cut)} \qquad (2)$$

Where, width of cut (in mm) = (Desired dimension – Actual dimension).

Wire surface after machining was analyzed by using JEOL JSM-6010LA SEM equipped with EDS facility.

Table 2: WEDM variable process parameters and their levels

S. No.	Parameters	Levels				
1.	Pulse on time (µs)- T_{ON}	105	110	115	120	125
2.	Pulse off time (µs)-T_{OFF}	52	55	57	60	63
3.	Spark gap voltage (V)-SV	35	45	55	65	75
4.	Wire tension (N)-WT	2	4	5	6	8
5.	Wire feed rate (m/min)-WF	4	6	8	10	12

3. RESULTS AND DISCUSSION

3.1 Wire Wear Ratio and Dimensional Deviation

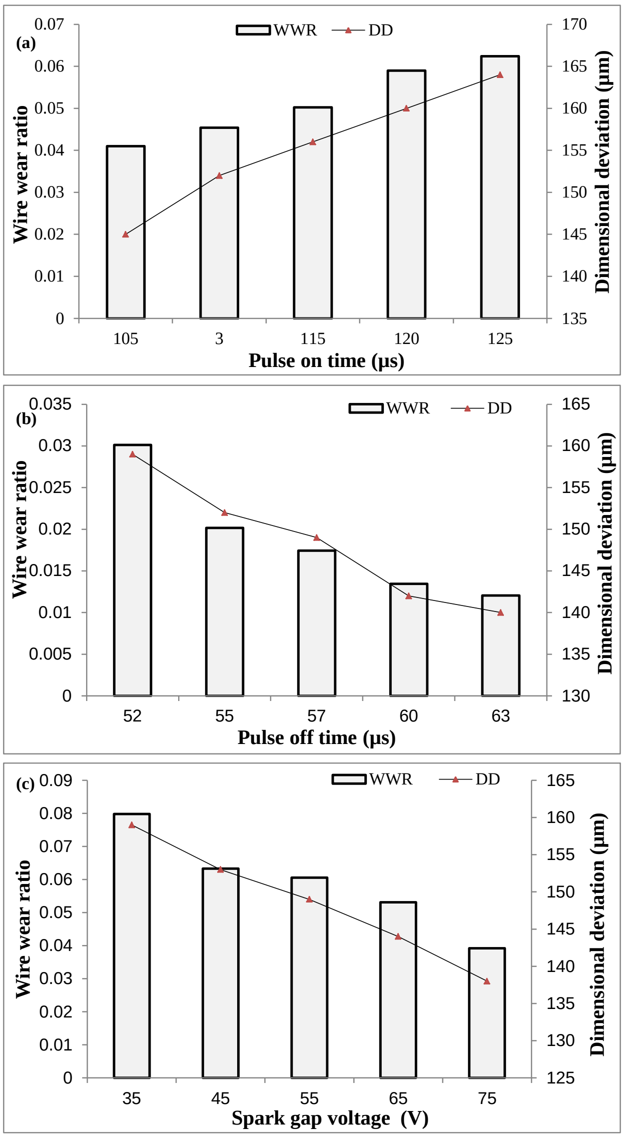
The effect of WEDM process parameters on WWR and DD are depicted in Figs. 2 (a) to (e). The volume eroded from wire surface is strongly depends on discharge (spark) energy [15]. Figure 2 (a) shows that WWR increases with the increase in pulse on time. As pulse duration increases, the discharge energy as well as the intensity of spark increases and hence the removal rate of wire material increased. Unlike pulse on time, at lower spark gap voltage and pulse off time, the discharge energy is more. Because at lower spark gap voltage (SV), the gap between two consecutive sparks is narrowed which produces high discharge energy per unit time and hence WWR is higher at lower SV.So, wire wear ratio is higher at lower spark gap voltage and pulse off time. From Figs. 2 (b) and (c), it can be observed that WWR is higher at the lower value of pulse off time and spark gap voltage. Wire tension has the insignificant effect on WWR as can be seen in Fig. 2(d). Figure 2 (e) shows the inverse relation of WWR with wire feed rate. WWR decreases with increasing wire feed rate because, at higher wire feed rate, the number of craters formed on wire surface decreased significantly [16, 17].

Similar to WWR, the DD is also strongly influenced by discharge energy. DD increases with increasing pulse on time and decreasing pulse off time as shown in Figs. 2 (a) and (b). The discharge is increased at lower pulse off time and higher pulse on time. The wire experiences an impact force, during every individual spark discharge, which acts in reverse direction of the occurrence of discharge and thus DD increases.

DD decreases with the increase in SV, because at higher SV cutting speed decreases and erosion process slows down. So, at slower erosion process high dimensional accuracy is achieved and finally, DD decreases [13]. Figure 2 (c) depicts the reverse relation of DD with SV. DD increases with the increase in WT as can be seen in Fig. 2 (d). Because at higher wire tension, the phenomena of wire bending are controlled which leads to a dynamic stable condition of the diameter and the depth of the crater leading to higher DD[18]. Wire feed rate has the inconsequential effect on DD as shown in Fig. 2 (e).

3.2 Wire Surface Topography

The microstructural changes in surface occur due to thermal stresses developed at the interface zone between the tool and workpiece. Wire surface topography before and after machining is represented in Figs. 3 (a) and (b) respectively. SEM micrograph of wire surface after machining shows the presence of many bulges of debris, craters, microcracks, voids, and the re-solidified layer of molten material on the wire surface. In EDWC process, the machined surface consists of small spherical craters due to the removal of material by individual sparks.



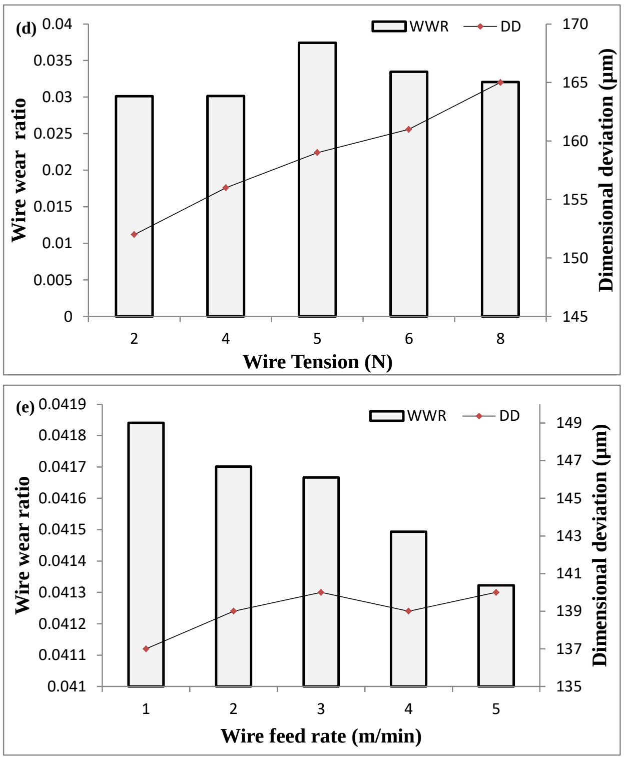
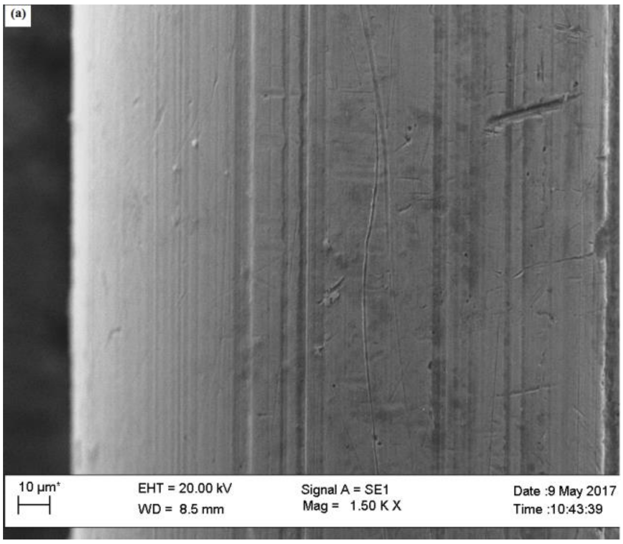


Fig.2. Effect of process parameters (a) pulse on time (b) pulse off time (c) spark gap voltage (d) wire tension and (e) wire feed rate on wire wear ratio and dimensional deviation



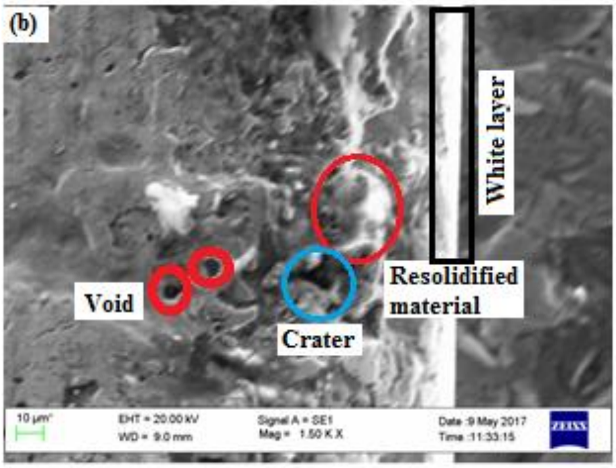


Fig.3.surface topography of brass wire (a) before machining (b) after machining

4. CONCLUSIONS

Based on experimental results and analysis, the following significant conclusions can be made:

1. Wire wear ratio is strongly influenced by discharge energy and wire feed rate, however, wire tension has the minor effect on it. WWR increases with increasing pulse on time whereas decreases with the increase in pulse off time, spark gap voltage and wire feed rate.
2. DD is also strongly affected by discharge energy and wire tension; however, wire feed rate has insignificant for it. DD increases with increasing pulse on time and wire tension whereas decreases with the increase in spark gap voltage and pulse off time.
3. Wire surface after machining is characterized for many craters, voids, re-solidified materials, and debris.

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