Experimental study on Response Parameters of Ni-rich NiTi Shape Memory Alloy during Wire Electric Discharge Machining

Himanshu Bisaria, Pragya Shandilya*

Department of Mechanical Engineering, Motilal Nehru National Institute of Technology Allahabad, Allahabad-211004, India

*Corresponding author: pragya20@mnnit.ac.in

Abstract. Nowadays NiTi SMAs are gaining more prominence due to their unique properties such as superelasticity, shape memory effect, high fatigue strength and many other enriched physical and mechanical properties. The current studies explore the effect of machining parameters namely, peak current (Ip), pulse off time (TOFF), and pulse on time (TON) on wire wear ratio (WWR), and dimensional deviation (DD) in WEDM. It was found that high discharge energy was mainly ascribed to high WWR and DD. The WWR and DD increase with the increase in pulse on time and peak current whereas high pulse off time was favourable for low WWR and DD.

1. Introduction

Recently, Ni-rich NiTi shape memory alloys (SMAs) are recognized for their exclusive properties, namely, shape memory effect (SME), superelasticity/pseudoelasticity (SE) and enriched mechanical properties [1]. These alloys are the genuine candidate for biomedical, aerospace, robotics and automotive industries due to their high corrosion resistance, high strength and high work density [2, 3]. However, their machining by traditional machining practices is still extremely challenging. To surmount these hurdles, various non-traditional machining approaches is opted by many researchers for successful machining of SMAs. WEDM (a special variant of EDM) is an advanced machining process which uses a travelling conductive wire as an electrode. Due to intense thermal energy from the spark between wire electrode and workpiece, the material is removed from workpiece as well as wire [4, 5]. WEDM is known for its accuracy and precision. In WEDM, around 70% of the machining cost is associated with wire used [6]. The study of wire wear phenomena is vital for economic machining in WEDM. The similar severe problems such as machine surface’s hardening, tool wear, large cutting time and poor surface quality during traditional machining of SMAs faced by many researchers [7,8]. Hesish et al. [9] observed the machinability of TiNiX(X=Zr/Cr) SMAs in WEDM process. It was found that the product of the thermal conductivity in WEDM of SMAs can be used as a machining characteristic. Manjaiah et al. [10] examined the effect of input variables (servo voltage, pulse duration, flushing pressure, pulse off time, & wire speed) on MRR & surface roughness (SR). It was noticed that pulse on time had maximum contribution followed by pulse off time and pressure of dielectric for maximizing MRR and minimizing surface roughness for Ti50Ni50 SMA. Kumar et al. [11] studied the effect of machining characteristics on cutting rate, SR, DD and WWR in WEDM. It was found that performance parameters were significantly influenced by Ip, TON, TOFF and spark gap voltage.

From the detailed scrutiny of literature review, it can be concluded that limited research work has been reported on WEDM of Ni-rich NiTi SMAs. Very few works on experimental studies on WWR and DD in WEDM of SMAs have been reported. The aim of this research is to study the effect of machining characteristics such as Ip, TON and TOFF on WWR and DD in WEDM of Ni55.7Ti SMA.

2. Material and Methodology
2.1 Material
Ni-rich NiTi (Ni55.7Ti) SMA was selected for this experimental investigation. Ni55.7Ti SMA in a square plate of dimensions $165 \times 165 \times 6$ mm$^3$ was selected. Energy dispersive X-ray spectrometry (EDS) was used to identify the chemical composition of Ni55.7Ti SMA. The chemical composition of Ni55.7Ti SMA and EDS analysis is displayed in Figure 1.

![Figure 1. EDS analysis of Ni55.7Ti SMA](image)

2.2 Methodology
The experiments were conducted on a four-axis CNC based Electronica Supercut 734 WEDM as shown in Figure 2. The three significant input electrical parameters of WEDM namely, pulse on time ($T_{ON}$), pulse off time ($T_{OFF}$) & peak current (IP) were selected for experimentation. The effect of individual parameters on WWR and DD was analyzed using one factor at a time (OFAT) approach. The variable parameters and their levels are given in Table 2. Table 3 represents fixed parameters which were kept at fixed value throughout the experiment. A square part of dimensions $10 \times 10 \times 6$ mm$^3$ was cut from plate. 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) [11].

$$WWR = W_f/W_i$$

(1)

Where $W_f$ = Loss in weight of wire = $W_f-W_i$, $W_i$ = Initial weight of wire per unit length i.e. weight of wire after machining and $W_i$ = Initial weight of wire per unit length i.e. weight of wire before machining. The term dimensional deviation may define in terms of deviation of wire trajectory i.e. the difference between 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) [11].

$$Dimensional \Deviation \ (DD) = 0.5 \ (width \ of \ cut)$$

(2)

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

| Table 1. Variable parameters of WEDM |
|-------------------------------------|
| S.No. | Input parameter | Levels | Response |
|-------|-----------------|--------|----------|
| 1.    | Pulse on time ($\mu$s) | 18 | 20 | 22 | 24 | 26 | WWR |
| 2.    | Pulse off time ($\mu$s) | 48 | 49 | 50 | 51 | 52 | DD |
| 3.    | Peak current (A) | 160 | 170 | 180 | 190 | 200 |

| Table 2. Fixed parameters of WEDM |
|-----------------------------------|
| S.No. | Parameter | unit | value |
|-------|-----------|------|-------|

1. Spark gap voltage (SV) \( V \)  
2. Wire feed rate \( m/\text{min} \)  
3. Wire tension \( N \)  
4. Brass wire diameter \( \text{Mm} \)  
5. DI-water (dielectric pressure) \( \text{kg/cm}^2 \)  
6. Working temperature \( ^\circ\text{C} \)

| No. | Parameter                                      | Unit        | Value |
|-----|-----------------------------------------------|-------------|-------|
| 1   | Spark gap voltage                             | \( V \)     | 7     |
| 2   | Wire feed rate                                | \( m/\text{min} \) | 4     |
| 3   | Wire tension                                  | \( N \)     | 5     |
| 4   | Brass wire diameter                           | \( \text{Mm} \) | 0.25  |
| 5   | DI-water (dielectric pressure)                 | \( \text{kg/cm}^2 \) | 7     |
| 6   | Working temperature                           | \( ^\circ\text{C} \)  | 25    |

**Figure 2.** Four-axis CNC type Electronica Supercut 734 WEDM and job profile

### 3. Results and Discussion

The variation of wire wear ratio and dimensional deviation against pulse on time is displayed in Fig. 3. As can be seen, the WWR and DD increased with the increase in pulse on time. The higher the pulse on time, the higher the discharge energy, as well as the spark’s intensity, is. The wire experiences an impact during every single spark discharge which acts in the opposite direction of discharge occurrence hence DD increased with the increase in \( T_{ON} \). The WWR and DD at higher pulse on time are approximately increased by 52 % and 14 % respectively as compared to lower \( T_{ON} \). At high discharge energy, material removal rate increased and consequently, more wear of wire occurred. Figure 4 depicts the effect of pulse off time on WWR and DD. It can be noticed that both WWR and DD decreased with the increase in pulse off time. Unlike \( T_{ON} \), at higher pulse off time, the intensity of spark and discharge energy decreased and therefore WWR and DD decreased. The WWR and DD at lower pulse off time are approximately increased by 2.5 times and 1.2 times respectively as compared to higher pulse off time. The effect of peak current on WWR and DD is represented in Fig. 5. Like \( T_{ON} \), the WWR and DD increased with the increase in peak current. In the similar fashion to pulse on time, at higher peak current, the discharge energy increased which facilitate the melting of workpiece material and wire too. So, at higher \( I_p \) WWR & DD increased. The WWR and DD at higher peak current are approximately increased by 2 times and 1.2 times respectively.
Figure 3. Effect of pulse on time on wire wear ratio and dimensional deviation

Figure 4. Effect of pulse off time on wire wear ratio and dimensional deviation
Figure 5. Effect of peak current on wire wear ratio and dimensional deviation

4. Conclusions
This experimental study mainly concentrated on the influence of machining parameters such as of $T_{ON}$, peak current and $T_{OFF}$ on wire wear ratio and dimensional deviation in WEDM of Ni55.7Ti SMA. From the obtained experimental results and analysis, it can be summarized that high pulse on time, peak current and low pulse off time are mainly ascribed to high wear of wire and dimensional deviation.

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