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Electric Discharge Wire Cutting Performance of $Ni_{54.1}Ti_{45.9}$ Shape Memory Alloy

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Abstract

Shape memory alloy (SMA) titanium with a nickel base is becoming more and more desirable for usage in various applications. These SMAs provide several difficulties during ordinary machining. In the ongoing research, the wire-electric discharge procedure has recently been attempted to be used to manufacture the super-elastic nickel-titanium ($Ni_{54.1}Ti_{45.9}$) material. The good performance of NiTi in medical and other applications depends on effective and net-shape machining. The $Ni_{54.1}Ti_{45.9}$ alloy's surface characteristics are examined using a brass tool electrode and the WEDM (wire electrical discharge machining) technique, as well as the effects of changing process parameters. The purpose of this experiment was to use a one-factor-at-a-time method to determine how the WEDM variable parameters of wire feed rate (WF), pulse on time (T_{ON}), pulse off time (T_{OFF}), peak current (IP), wire tension (WT), affected the recast-layer thickness (RLT), and surface roughness. Following the results, it was determined that T_{ON} was the most effective parameter for the RLT.

Keywords

Wire electrical discharge machining, $Ni_{54.1}Ti_{45.9}$, Recast-layer thickness, Shape memory alloy, Energy dispersive X-ray spectroscopy

Introduction

Shape-memory effect (SME) has an exclusive property, i.e., biocompatibility and super elasticity. Thus, NiTi alloy is classified as a smart material [1-2]. As a result, the majority of applications for this material include orthopedic implants, orthodontics, micro-electro-mechanical systems (MEMS), cardiovascular stent technology in aerospace, applications of switches (electrical), etc. SMEs are known as smart materials which can alter their own size and shape and then change back to that shape when heat, magnetic flux or pressures are applied. Because martensitic phase transitions can be reversed, they can lead to stress, more elevated pressure, and work efficiency [1-3]. This alloy has exceptional action, vibration damping, and sensing qualities and is small, strong, light, silent, biocompatible, and environmentally friendly. Since its invention in 1932, there has been a great advancement, and today, multiple kinds of alloys are available in materialistic phases for various uses. Ni-Ti-based SMA is used a lot in the biomedical and engineering fields because it has better wear resistance, better corrosion resistance, better thermal stability, and is biocompatible. It is appropriate for biomedical implants because the titanium components of the NiTi alloys include a vindicatory layer (TiO_2) that prevents the Ni ions from discharging into the biofluid. Applications for $Ni_{54.1}Ti$ are typically present in the biomedical field, particularly in orthodontics [1, 3], where it is frequently employed alongside stainless steel and Co-Cu alloy. In other words, typical stress-strain behaviour, low thermal conductivity, high ductility, and high level of labor intensity. SME machining using conventional methods is typically difficult [2, 4].

Conventional techniques have a large environmental impact, poor surface quality, excessive burr development, resource consumption, high energy, and increased manufacturing and processing costs. It also entails the creation of cutting-edge processes for making shape memory alloys. Complex implants and structures made of the $Ni_{54.1}Ti_{45.9}$ alloy are required for biomedical applications. For difficult-to-work with materials that require complicated shapes and features, wire-EDM is a non-traditional approach [5, 6]. Therefore, wire-EDM has been chosen to machine the $Ni_{54.1}Ti_{45.9}$ alloy material in the current experiments in order to attain greater machinability. The WEDM technique was carried out on thermoelectrical erosion theory in which spark generation between the workpiece (as an anode) and the wire electrode (as a cathode) while being encircled by the appropriate dielectric fluid [7]. A thorough investigation of different NiTi material grades on WEDM was carried out by Manjaiah et al. [8, 9]. Soni et al. [10] carried out an experimental examination of the impact of WEDM process parameters on the machining properties and surface characteristics of $Ti_{50}Ni_{40}Co_{10}$ SMA. They concluded that the discharge energy had a significant impact on microhardness (T_{ON}, T_{OFF}, and SV) and the RLT. Klocke et al. [11] also found that when die-sinking EDM was used on AISI 4140 steel, the thickness of the recast-layer got thinner when the discharge energy got lower. Due to the study of the machinability of TiNiCu SMA under WEDM, Manjaiah et al. [12] found that RLT increased as the discharge energy rise, i.e., with a high T_{ON} and a low T_{OFF}. The objective of this experimental examination was to examine how WEDM process parameters such as T_{ON}, IP, WT, T_{OFF}, and WF on RLT affected various elements of surface integrity for $Ni_{54.1}Ti_{45.9}$ SMA. The recast-layer was examined using scanning electron microscope (SEM) with energy dispersive X-ray spectroscopy (EDX).

Experimental procedure

Materials

For this investigational examination, a square $Ni_{54.1}Ti_{45.9}$ (at %) SMA plate with dimensions of 130 x 130 x 6 mm^3 and a 6.7 g cm^3 density was considered. Elemental composition of $Ni_{54.1}Ti_{45.9}$ SMA as determined by EDX analysis, as presented in figure 1.

Experimental details

EA 4-axis CNC WEDM (Supercut-743) was used to machine $Ni_{54.1}Ti_{45.9}$ SMA. It has been investigated how WEDM parameters like IP, T_{ON}, WF, T_{OFF}, and WT affect RLT. Table 1 and table 2 list the fixed and several parameters taken into consideration under investigation.

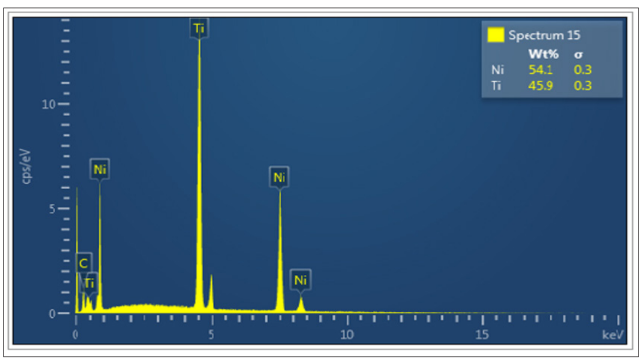

Figure 1: Elemental composition of $Ni_{54.1}Ti_{45.9}$ SMA using EDX.

Using the ImageJ software, length of the recast-layer and area were estimated, and RLT was measured on the machined surface. Also, RLT was determined using the following formula:

$$RLT=RLA/RLL \quad (1)$$

Where, RLL is the length of the recast-layer and RLA is its area.

Table 1: Levels and range of process variables.

S. No.	Parameters	Symbol	Levels		
1.	Pulse on time (µs)	T_{ON}	18	22	26
2.	Pulse off time (µs)	T_{OFF}	40	48	56
3.	Peak current (amp)	IP	160	180	200
4.	Wire tension (N)	WT	4	5	6
5.	Wire feed rate (m/min)	WF	3	4	5

Table 2: Fixed parameters for $Ni_{54.1}Ti_{45.9}$ SMA in WEDM.

S. No.	Machining Parameters	Fixed value
1.	Wire	Zinc coated (Ø 0.25 mm)
2.	Pulse peak voltage (V)	2
3.	Servo feed (machine unit)	1120
4.	Flushing pressure (kg/cm²)	1
5.	Dielectric conductivity (µs/m)	± 20 - 24
6.	Working temperature (°C)	25
7.	Dielectric fluid	De-ionized water

Results and Discussion

The magnitudes of the responses in relation to the various WEDM process parameter levels at the fixed parameters are compiled.

Recast layer thickness

WEDM is a thermal process; therefore, fasting heating and quenching of the dielectric generate substantial temperature variations on the workpiece's surface. The molten material on the outermost surface resolidifies due to the abrupt drop in temperature from the very elevated temperature (10,000 °C) state, and this resolidified layer of changing phases is known as the recast-layer [10-13]. Figure 2a and 2b depict, respectively, the recast-layer generated at a greater level of T_{ON} and a lower

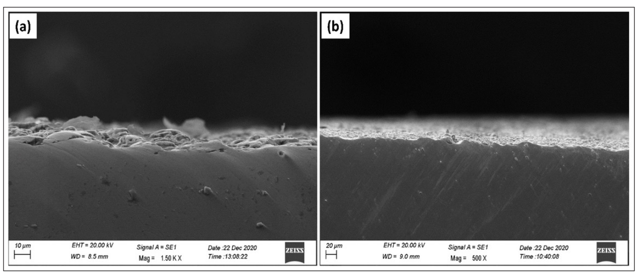

Figure 2: Recast-layer developed at **(a)** longer pulse on time or **(b)** shorter pulse off time on the machined surface.

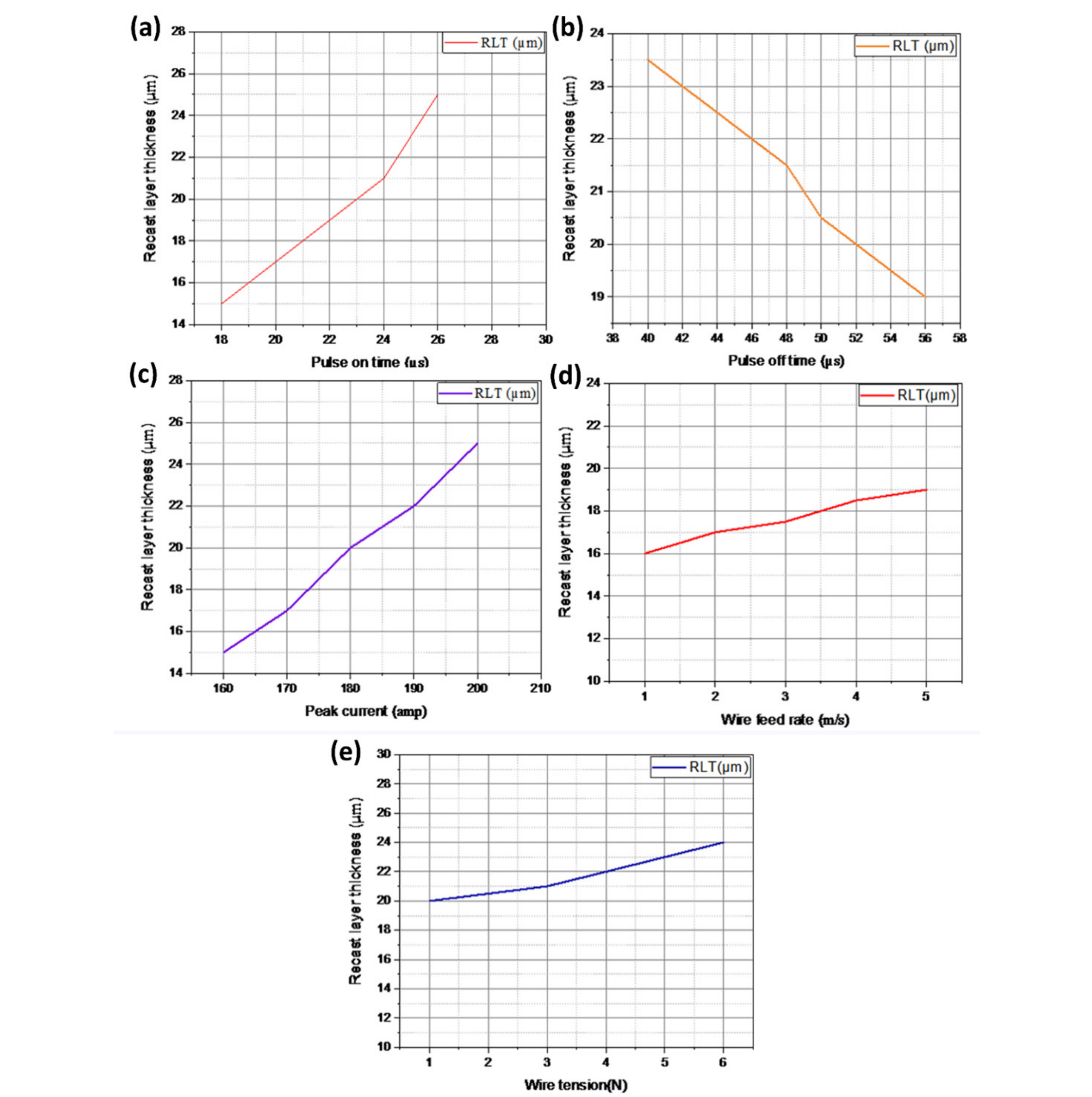

Figure 3: Effect of **(a)** T_{ON}, **(b)** T_{OFF}, **(c)** IP, **(d)** WF, and **(e)** WT on RLT of $Ni_{54.1}Ti_{45.9}$ SMA during the WEDM process.

level of T_{OFF} on the machined surface. The values of parameters have a significant impact on how thick the recast-layer that results from this process is. Figure 3a - 3e show the impact of WEDM variable factors on RLT for $Ni_{54.1}Ti_{45.9}$ SMA. The fluctuation of RLT at various T_{ON} levels is shown in figure 3a. The RLT, it can be assumed, grew as the T_{ON} increased. The influence of T_{OFF} and IP on RLT is depicted in figure 3b and 3c, respectively. As T_{ON} grew, the discharge energy also raised, causing more material to melt. As a result, a thick RLT was created at a top level of T_{ON} [12]. In contrast to T_{ON}, a substantial recast-layer develops at lesser levels of T_{OFF} and higher level of IP. This is due to higher discharge energy at lower T_{OFF} and IP levels, which enhances heat transmission into the workpiece and causes sufficient material to melt and resolidify on the machined surface [14]. The impact of WF and WT on RLT is depicted in figure 3d and 3e. The diagrams show that neither WF nor WT have a significant impact on RLT. The amounts of these factors have a small effect on the discharge energy; hence WF and WT only minimally affect RLT.

Conclusions

Current research focuses on the WEDM of $Ni_{54.1}Ti_{45.9}$ SMA with zinc coated brass wire electrode material. The following conclusions drawn from experimental analysis are as follows.

1. It's concluded that Spark-on-time, Spark-off-time, and IP are the affecting factor for RLT, whereas WF and WT did not affect the responses.

2. In this experimental research, the parametric examination of the effects of WEDM variable parameters on RLT is the primary emphasis.
3. On the machined surface of $Ni_{54.1}Ti_{45.9}$ SMA, a deep resolidified layer was seen at greater T_{ON}; however, at more IP and T_{OFF}, a thin RLT was seen.

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Conflict of Interest

The authors declare no conflict of interest.

Credit Author Statement

Deepak Kumar Gupta: Conceptualization, Experimentation, Results and Discussion, Writing - original draft preparation; Avanish Kumar Dubey: Writing - review and editing; Supriya Yadav: Supervision, writing - review and editing. All the authors read and approved the manuscript.

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