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Effect of electrode material in wire electro discharge machining characteristics of $Ti_{50}Ni_{50-x}Cu_x$ shape memory alloy

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ABSTRACT

TiNiCu alloy belongs to new class of shape memory alloy (SMA), which exhibits superior properties like shape memory effect, super elasticity and reversible martensitic transformation phase and thus find broad applications in actuators, micro tools and stents in biomedical components. Even though, SMA demonstrates outstanding property profile, traditional machining of SMAs is fairly complex and hence non-traditional machining like wire electric discharge machining (WEDM) has been performed. Hence, there is a need to investigate the WEDM performance characteristics of shape memory alloys due to excellent property profile and potential applications. In the present investigation, various machining characteristics like material removal rate (MRR), surface roughness, surface topography and metallographic changes have been studied and the influence of wire material on TiNiCu alloy machining characteristics has also been evaluated through ANOVA. $Ti_{50}Ni_{50-x}Cu_{x=10,20}$ was prepared by vacuum arc melting process. The proposed alloy as-cast material exhibits austenite property (B2 phase) and having higher hardness when compared to TiNi alloy. The investigation on WEDM of $Ti_{50}Ni_{50-x}Cu_x$ alloy reveals that the machining parameters such as servo voltage, pulse on time and pulse off time are the most significant parameters affecting MRR as well as surface roughness using both brass and zinc coated brass wires. However, machining with zinc coated brass wire yields reduced surface roughness and better MRR and also produces less surface defects on the machined surface of $Ti_{50}Ni_{50-x}Cu_x$ alloys.

1. Introduction

In recent years, the advanced engineering materials such as titanium–nickel based shape memory alloys (SMAs) are normally used in medical devices, surgical instruments (ASTM F6023-12) and industrial engineering applications. The medical applications include eyeglass frames, surgical stents, orthodontic arch wires and active catheters. The various industrial engineering applications are the functional devices such as fasteners, sealing and coupling, aerospace actuators (magnetic), sensors and micro electromechanical devices (MEMS), cellular phone antennas, fuel injector and small helicopter rotor [1]. SMAs exhibit excellent properties such as quick actuation response, unique properties like superplasticity and shape memory effect (SME), high wear resistance, corrosion resistant, greater ductility, high specific strength and modulus, good fatigue property and high bio-compatibility [2,3]. SMAs are typically known for SME and pseudoelasticity (PE) properties. Among the SMAs, TiNi based Cu and Fe based SMAs are widely accepted in industries [2,4].

The addition of Cu in TiNi SMAs not only increases the ductility but also enhances the machinability characteristics and thereby reduces the liquidus temperature. This will in turn decreases the hysteresis and de-twinning stress of the martensite [3,5]. Cu based SMAs have strengthened the parent phase due to the refinement of grain size. The development of these SMAs in numerous sectors requires desired components for particular operation and hence machining of these alloys is essential. The machining of SMAs is comparatively important and becomes integral part in the manufacture of the several components. During conventional machining of these SMAs, higher tool wear and lower surface quality are frequently observed due to higher strain hardening effect, pseudoelastic behavior and high toughness [6–8] To overcome these problems, non-conventional machining processes are successfully used to machine these alloys. Wire-electro discharge machining (WEDM) is an advanced method that has revolutionized in the field of cutting tool, die and mold making industries.

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Hsieh et al. [9] studied the shape recovery ability and various performance characteristics of TiNiZr/Cr SMAs in WEDM. They found that the feed rate of wire electrode increases with increased pulse on time. It was also observed that even though the WED-machined SMA exhibits a good shape recovery, but a slight degradation of shape recovery occurs due to the depression of the recast layer. Chen et al. [10] investigated the EDM characteristics of TiNiZr and TiNiCr ternary SMA and reported that the ED-machined TiNiX alloys could exhibit perfect shape recovery at normal bending strain, but slight degradation of shape recovery could occur at higher bending strain due to constrained effect on TiNiX matrix by recast layer. Theisen and Schuermann [11] studied the EDM of NiTi alloy behavior and their study clearly reveals that the precipitation of titanium carbide in the heat-affected zone could reduce the shape memory effect. Alidoosti et al. [12] performed experiments on EDM of nickel titanium SMA using two electrodes, namely, tungsten–copper and copper using full factorial design (FFD) to analyze the various machining performance. Their investigations evidently indicate that selecting proper electrode with higher melting stability that creates an acceptable surface condition and machining speed could increase the production. LotfiNeyestanak and Daneshmand [13] studied the shape recoverability and microhardness of machined surface of NITINOL-60 by considering recasting and resolidified layer on the machined surface. The formation of surface layer on machined surface caused changes in both physical and mechanical properties of SMA.

Even though, a few studies have been reported in the literatures on WEDM of TiNi SMA, as per authors' knowledge, no methodical work has been carried out to analyze the machining performance WEDM of TiNi SMA. Our current research is mainly focused on WEDM of $Ti_{50}Ni_{40}Cu_{10}$ and $Ti_{50}Ni_{30}Cu_{20}$ alloys using two different electrodes, namely brass and zinc coated brass wires and to choose the best suited electrode for machining of these alloys. The influence of various process parameters such as pulse on time, pulse off time, servo voltage, wire speed and servo feed on various WEDM performance characteristics like material removal rate (MRR), surface roughness, surface topography and metallographic changes have been studied. The minimum number experiments were planned as per orthogonal array (OA) to analyze the various WEDM characteristics of newly developed TiNi SMAs.

2. Experimental work

2.1. Casting procedure

$Ti_{50}Ni_{(50-x)}Cu_x$ SMAs were prepared by using vacuum arc melting (VAM) technique. Titanium, nickel and copper with a purity of 99.2, 99.89 and 99.89 respectively of 8 g in total weight was filled into the copper mold and then processed by inert argon atmosphere using a tungsten electrode. The pure metal rods (Ti, Ni and Cu) were cut into very small pieces, weighed using an electronic balance (0.0001 g accuracy) and then charged into the furnace for button melting operation. A vacuum was created using the standard procedure up to 10^{-5} mbar and then argon gas was purged into the chamber. Pumping the system flushed out the gas and the procedure for vacuum creation was carried out to achieve a very good vacuum of 10^{-5} mbar and then followed by backfilling of argon gas. This is done in order to remove any impurities present in the chamber.

2.2. Experimental details

In the current research, the experiments were performed on '*ELECTRONICA*' WED machine. Five process parameters, namely, pulse on time, pulse off time, servo voltage, wire speed and servo feed were identified and the ranges for each of process parameters were determined through preliminary experiments. Each process parameter was investigated at three levels to study the non-linear effect of the process parameters. The selected process parameters as well as their identified levels for single pass cutting operation during WEDM of TiNi SMA and the proposed experimental design matrix planned as per L_{27} orthogonal array (OA) for the current investigation is presented in Tables 1 and 2 respectively. The parameters such as peak current of 12 A, de-ionized water as dielectric fluid with pressure 12 kg/cm^2, wire diameter of 0.25 mm and 900 g-wire tension were kept constant throughout the experimentation.

Table 1
Controllable parameters and their levels.

Code	Parameter	Level 1	Level 2	Level 3
T_{on}	Pulse on time (μs)	120	125	130
T_{off}	Pulse off time (μs)	48	55	62
SV	Servo voltage (V)	20	50	80
WS	Wire speed (m/min)	5	10	15
SF	Servo feed (mu)	2160	2570	2990

Two suitable wires, namely, brass and zinc-coated brass were selected based on the previous research [16]. Zinc wire consists of 65% zinc and 35% copper, whereas zinc coated brass wire consists of 5 μm zinc coating over a standard brass wire. These wires are utilized for better cutting of titanium-based alloy and having a reduced surface roughness. These wires are also utilized in those circumstances, in which brass wires produce unacceptable brass plating on the workpieces.

2.3. Measurement of MRR and surface roughness

The stopwatch was used to determine the machining time and the material removal rate (MRR) was computed as follows:

$$MRR = V_c * b * h\,(mm^3/min) \quad (1)$$

Table 2
Experimental layout plan as per L_{27} orthogonal array.

Trial no.	Levels of process parameter settings				
	T_{on}	T_{off}	SV	WS	SF
1	1	1	1	1	1
2	1	1	1	1	2
3	1	1	1	1	3
4	1	2	2	2	1
5	1	2	2	2	2
6	1	2	2	2	3
7	1	3	3	3	1
8	1	3	3	3	2
9	1	3	3	3	3
10	2	1	2	3	1
11	2	1	2	3	2
12	2	1	2	3	3
13	2	2	3	1	1
14	2	2	3	1	2
15	2	2	3	1	3
16	2	3	1	2	1
17	2	3	1	2	2
18	2	3	1	2	3
19	3	1	3	2	1
20	3	1	3	2	2
21	3	1	3	2	3
22	3	2	1	3	1
23	3	2	1	3	2
24	3	2	1	3	3
25	3	3	2	1	1
26	3	3	2	1	2
27	3	3	2	1	3

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