Available online at www.sciencedirect.com

ScienceDirect

Trans. Nonferrous Met. Soc. China 24(2014) 3201−3209

Transactions of
Nonferrous Metals
Society of China

www.tnmsc.cn

Wire electric discharge machining characteristics of titanium nickel shape memory alloy

M. MANJAIAH[1], S. NARENDRANATH[1], S. BASAVARAJAPPA[2], V. N. GAITONDE[3]

1. Department of Mechanical Engineering, National Institute of Technology, Surathkal, Karnataka, India;
2. Department of Studies in Mechanical Engineering, University B.D.T. College of Engineering, Davangere-577 004, Karnataka, India;
3. Department of Industrial and Production Engineering, B. V. B. College of Engineering and Technology, Hubli-580 031, Karnataka, India

Received 29 November 2013; accepted 15 March 2014

Abstract: TiNi shape memory alloys (SMAs) have been normally used as the competent elements in large part of the industries due to outstanding properties, such as super elasticity and shape memory effects. However, traditional machining of SMAs is quite complex due to these properties. Hence, the wire electric discharge machining (WEDM) characteristics of TiNi SMA was studied. The experiments were planned as per L_{27} orthogonal array to minimize the experiments, each experiment was performed under different conditions of pulse duration, pulse off time, servo voltage, flushing pressure and wire speed. A multi-response optimization method using Taguchi design with utility concept has been proposed for simultaneous optimization. The analysis of means (ANOM) and analysis of variance (ANOVA) on signal to noise (S/N) ratio were performed for determining the optimal parameter levels. Taguchi analysis reveals that a combination of 1 μs pulse duration, 3.8 μs pulse off time, 40 V servo voltage, 1.8×10^5 Pa flushing pressure and 8 m/min wire speed is beneficial for simultaneously maximizing the material removal rate (MRR) and minimizing the surface roughness. The optimization results of WEDM of TiNi SMA also indicate that pulse duration significantly affects the material removal rate and surface roughness. The discharged craters, micro cracks and recast layer were observed on the machined surface at large pulse duration.

Key words: TiNi shape memory alloy; wire electric discharge machining (WEDM); surface roughness; material removal rate; surface morphology

---

1 Introduction

Titanium nickel (TiNi) shape memory alloy (SMA) has maximum recoverable strain up to 8% compared with other SMAs, and hence finds broad applications in actuators, vibration and sesmic absorbers [1], orthodontic springs [2] , endovascular stents [3] and coupling systems for pipes [4]. TiNi is one of the most important biomaterials used in the field of medical applications due to its biocompatibility, better corrosion resistance, superelasticity and shape memory effect (SME). However, the development of this material causes difficulties in manufacturing process. The conventional machining of TiNi SMAs is very difficult due to poor thermal conductivity. Because of lower thermal conductivity, the generated heat is concentrated on the tool tip, leading to higher tool wear, severe strain hardening, high toughness and viscosity and unique property of super elastic behavior [5,6]. To overcome these difficulties, special machining techniques, such as electric discharge machining (EDM) [7], wire electric discharge machining (WEDM) [8] and laser machining [9] have been performed for machining TiNi alloys.

Presently, WEDM is a prevalent technique, which is typically suitable for precision engineering applications of conductive materials. During WEDM, the damaging impacts on surface integrity of machined surface, such as craters, micro voids, recast layer and heat affected zone, are agreeable for cracking and reduction in fatigue strength [10]. Improving the surface quality and property by decreasing the formations of recast layer, cracks, oxides and carbide on machined surface can be achieved using optimal WEDM process parameters. Reduction in surface roughness can improve the fatigue strength, corrosion and wear resistance of the material [11].

Corresponding author: S. BASAVARAJAPPA; Tel: +91-9964068188; E-mail: basavarajappas@yahoo.com

DOI: 10.1016/S1003-6326(14)63461-0

The discharge current and pulse duration are the most significant parameters influencing the material removal rate and surface roughness. Optimum process parameter is crucial to reduce the machining cost and to machine intricate shapes with enhanced surface property [12]. FAN et al [13] developed a multi precision pulse power based micro controller unit to adjust the electric parameters. They reported that the best surface finish could be achieved by constant pulse interval and pulse duration with proper selecting capacitance. SELVAKUMAR et al [14] analysed the corner accuracy in WEDM of Monel 400 alloy. The studies indicated that the corner accuracy was more or less independent of sparking factors and primarily influenced by flushing height, job height and corner angle. Multi objective optimization in WEDM of Ti6242 alloy was performed by GARG et al [15] by integrating Box-Behnken design with genetic algorithm (GA). Recently, the machinability study in EDM of TiNi SMA has been carried out by ALIDOOSTI et al [7]. They found that the recast layer formed during machining, leading to higher surface hardness of the material. PROHASZKA et al [16] reported that the machining speed increased, primarily due to the presence of zinc in wire electrode.

Although some studies have been reported in the literatures on machining of TiNi SMA, no systematic work has been carried out to optimize the process parameters in WEDM of TiNi SMA. This work demonstrates the application of Taguchi method with the utility concept for multi-objective WEDM process optimization. The key advantage of Taguchi technique is that the method allows the process optimization with minimum number of experiments without the need for process model development [17,18]. Thus, by this method, it is possible to reduce the time and cost for experimental investigations and improve the performance characteristic with minimum experiments. Taguchi optimization technique is based on the concept of “robust design”, which aims at obtaining the solutions that make the designs less sensitive to the noise factors. Taguchi methods have been extensively applied in the process design, wherein the mathematical models for performance do not exist and the experiments are typically conducted to determine the optimum settings for design and process variables. However, Taguchi method is applied for a single performance characteristic, and hence several modifications were suggested to improve the original Taguchi method for multi response optimization [19]. The utility concept [20] employs the weighting factors to each of the signal to noise (S/N) ratio of the performance characteristics to acquire a multi-response S/N ratio for each trial of the orthogonal array (OA). In the present research work, the modified Taguchi method was used to find out the optimal process parameters, namely, pulse duration, pulse off time, servo voltage, flushing pressure and wire speed, to simultaneously optimize the material removal rate and surface roughness of workpiece during WEDM of TiNi SMA. Further, the surface morphology, recast layer, machined surface hardness and microstructure were also investigated.

2 Experimental

2.1 Taguchi method with utility concept

Taguchi method is used to find the optimum setting of control factors to make the product or process insensitive to noise factors. Taguchi design is based upon the technique of matrix experiments, known as orthogonal arrays [17,18], which allow the simultaneous effect of numerous factors to be studied proficiently. Taguchi method suggests signal to noise (S/N) ratio as the objective function for matrix experiments [17,18]. Taguchi method classifies objective functions into three categories, namely, smaller the better type, larger the better type and nominal the best type. The optimum level for a factor is the level that results in the highest S/N ratio value in the experimental region.

Taguchi technique with utility concept [20,21] involves assigning a weight for each performance characteristic. A weight to each S/N ratio of the characteristic is assigned and the weighted S/N ratio is summed for computing the performance of a multi-objective problem. If X_i is a measure of effectiveness of an attribute i and there are n attributes evaluating the outcome space, then the overall utility function is given by

$$U(X_1, \mathrm{X}_2, \cdots, X_n) = \sum_{i=1}^{n} U_i(X_i) \tag{1}$$

where $U_i(X_i)$ is the utility of the ith attribute. Depending on the requirements, the attributes may be given priorities and weights. Hence, the weighted form of Eq. (1) is as follows:

$$U(X_1, \mathrm{X}_2, \cdots, X_n) = \sum_{i=1}^{n} w_i U_i(X_i) \tag{2}$$

where $\sum_{i=1}^{n} w_i = 1$; w_i is the weight assigned to attribute i.

2.2 Workpiece material

The workpiece material used in the present investigation is $Ti_{50}Ni_{50}$ SMA specimen. Pure metal pieces from titanium rods containing 99% titanium (mass fraction) and nickel rods containing 99% nickel were mixed with equal mass (about 10 g) into copper mould melting chamber under vacuum. Prior to melting, the