Journal of King Saud University – Engineering Sciences (2016) **xxx**, xxx–xxx

King Saud University

Journal of King Saud University – Engineering Sciences

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ORIGINAL ARTICLES

Optimization of material removal rate during electrical discharge machining of cryo-treated NiTi alloys using Taguchi's method

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Received 21 January 2016; accepted 24 April 2016

KEYWORDS

NiTi alloy;
Taguchi's method;
ANOVA;
Material removal rate

Abstract To withstand in global manufacturing market it is necessary to acquire new technology for producing new products. To achieve this advanced material plays an important role. NiTi alloy is one such class of advanced material which has unique properties such as biocompatibility, high strength, high corrosion resistance, shape memory effect etc. Due to such property these alloys have wide application in the field of defence, aerospace, and medicine. As these applications required high accuracy, precision and high strength of NiTi these are difficult to machine by conventional machining processes. Hence to machine this advanced material non-conventional machining processes i.e. electric discharge machining is employed. However EDM has a wide range of process parameter and the aim of EDM users and manufacturers is to achieve optimal performance of EDM. In view of this objective the present study focuses on optimization of electric discharge machining process parameter for maximization of material removal rate while machining of NiTi alloy. In the present study gap current, pulse on time, pulse off time, workpiece electrical conductivity, and tool conductivity were considered as process variables. Experiments were carried out as per Taguchi's L_{36} orthogonal array. Based on the analysis it was found that work electrical conductivity, gap current and pulse on time are the significant parameters that affect the material removal rate. The optimized material removal rate obtained was 7.0806 mm^3/min based on optimal setting of input parameter.

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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jksues.2016.04.003

1. Introduction

To withstand in today's global manufacturing market it is necessary to adopt a new technology. The demand of this new technology is to acquire smart material such as NiTi alloy. NiTi is a class of smart material which possesses unique properties such as super elasticity, high strength, biocompatibility etc. NiTi alloy is widely used in the field of defence, aerospace, and medicine. As this alloy has unique property and application machining of this alloy is difficult using conventional machining processes therefore machining of this alloy is carried out using non-conventional machining processes such as electric discharge machining (EDM). EDM is the processes in which electrical energy is transferred into the thermal energy and erosive action leads to removal of material using flushing fluid.

Chen et al. (2007) studied the electro discharge machining of TiNiCr and TiNiZr ternary SMA. In this research conventional tungsten arc welding technique was implemented for the preparation of TiNiCr and TiNiZr ternary SMA. They concluded that MRR exhibits an inverse relationship to the product of the alloys melting temperature and thermal conductivity. Material removal rate will increase with both the increase in current as well as pulse on. From this research study they found that TiNiCr has a larger Ra value than TiNiZr and the thickness of recast layer varies with pulse on time and has a minimum value at maximum MRR. Chen et al. (2007) investigated the electro discharge machining of NiAlFe ternary SMA. The conventional tungsten arc welding technique is being practised to get ready NiAlFe. In this research it is concluded that MRR for NiAlFe is more as compared to TiNiZr and thickness of recast layer increases at the early stage and declines to a minimum value at the maximal MRR. Also the surface roughness (Ra) value of $Ni_{60}Al_{24.5}Fe_{15.5}$ is large as that of TiNiZr. Prihandana et al. (2011) investigated the effect of vibration on electric discharge machine. Material used for conducting these experiments is stainless steel (SS-304) with a low frequency vibration. This research study shows that use of a low frequency vibration improves the material removal rate and diminishes tool wear rate and surface finish. Singh et al. (2012) studied the effect of continuous and discontinuous vibration on work piece. In this study experiments were carried out using Taguchi's L_{18} orthogonal array. For experimentation high chromium high carbon steel is being used as work piece and copper is being used as tool material. On the basis of experiment they concluded that discontinuous vibrations give more MRR and TWR. Also the intensity of development of cracks is more in case of discontinuous vibration as compared with continuous vibration. Sabouni and Daneshmand (2012) conducted a research on EDM process parameter for NiTi SMA using graphite tool. For experimentation L_{18} Taguchi's DOE is being used. To improve the accuracy of experiments and to prevent the effect of oil-based dielectrics in reacting with the workpiece surface de-ionized oil water with an EC of less than 1 ms (micro Siemens) has been implemented along with the constant spray type of flushing. In this research study voltage is kept at 2 levels and pulse on, pulse off, gap current is at 3 levels. Daneshmand et al. (2013) conducted a research study on NiTi shape memory alloy using copper as a tool and de-ionized water as a flushing fluid. Experiments were carried out using Taguchi's L_{18} orthogonal array. From this study they concluded that material removal rate and tools wear rate increase with an increase in current and pulse on time, also tool wear rate with de-ionized water is less as compared to kerosene. Daneshmand et al. (2013) conducted a research on performance measure of output parameters of EDM using rotational tool, tool will be rotating at 200 rpm. Taguchi's DOE method is being implemented with L_{18} orthogonal array. Researchers investigated that MRR in rotational EDM is less as compared to traditional EDM by effect of current, pulse on, pulse off and voltage. Rotational tool decreases the breakdown resistance of dielectric hence MRR in rotational toll is less. Tool wear rate in case of rotational EDM decreases compared to traditional EDM with regards to gap current, pulse on time, pulse off time and gap voltage. This happens because there is decrease in the dielectric breakdown resistance by tool electrode rotation gap between tool and workpiece will increase and plasma channel becomes wide as a result of this electro discharge thermal energy distributes in large area so that electrical power density and MRR declines as a result TWR reduce consequently. Malek et al. (2011) investigated the electric discharge machining of B_4C–TiB_2 composites with respectively 30, 40 and 60 vol.% TiB_2. They found that 40 vol.% TiB_2 give optimal material removal rate and with an increase in concentration of TiB_2 surface roughness increases. They also found that an increase in the TiB_2 leads to an increase in thermal conductivity. Pradhan and Biswas (2009) investigated the effect of EDM processes parameter on AISI D2 tool steel with copper electrode. For experimentation they implemented response surface methodology. They concluded from this research that surface roughness has a direct relationship with the current and pulse on time. Sohani et al. (2009) investigated the effect of various shapes of electrode such as triangular, square, and circular on EDM processes parameter. They used response surface methodology for conduction of experiments. From this research study they concluded that the best tool shape for higher MRR and lower TWR is circular. They also concluded that MRR increases linearly and TWR non-linearly with the spark energy. Sohani et al. (2009) investigated the effect of various shapes of electrode such as triangular, square, and circular on EDM processes parameter. They used response surface methodology for conduction of experiments. From this research study they concluded that the best tool shape for higher MRR and lower TWR is circular. They also concluded that MRR increases linearly and TWR non-linearly with the spark energy. Lin et al. (2009) studied the magnetic force assist electrical discharge machine using Taguchi's L_{18} orthogonal array. From this research they concluded that MRR is improved and TWR is decreased as that of the conventional machining with magnetic assist EDM. They found that MRR is increased three times as that of conventional EDM. Manjaiah et al. (2015) investigated wire electric discharge machining of $Ti_{50}Ni_{50-x}Cu_x$ shape memory alloy. Performance measures considered during the machining were surface roughness, material removal rate, surface topography and metallographic changes. It was noted during the experimentation that with brass and zinc coated wire servo voltage, pulse off time and pulse on time were significant parameters which affect the MRR and surface roughness. Manjaiah et al. (2014) investigated machining of NiTi alloy on wire electric discharge machine. In this research experiments were conducted as per L_{27} orthogonal array. During this research anal-

Please cite this article in press as: Gaikwad, V., Jatti, V.S. Optimization of material removal rate during electrical discharge machining of cryo-treated NiTi alloys using Taguchi's method. Journal of King Saud University – Engineering Sciences (2016), http://dx.doi.org/10.1016/j.jksues.2016.04.003