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Investigation of surface integrity, material removal rate and wire wear ratio for WEDM of Nimonic 80A alloy using GRA and Taguchi method

Amitesh Goswami*, Jatinder Kumar

Department of Mechanical Engineering, National Institute of Technology, Kurukshetra 136 119, Haryana, India

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ABSTRACT

This paper presents the investigation on surface integrity, material removal rate and wire wear ratio of Nimonic 80A using WEDM process. Taguchi's design of experiments methodology has been used for planning and designing the experiments. All of the input parameters and two factors interactions have been found to be statically significant for their effects on the response of interest. SEM was performed on the machined samples to investigate the effect and microstructure of the samples after machining. A higher pulse-on time setting leads to thicker recast layer. At lower value of pulse-on time and higher value of pulse-off time, the wire deposition on the machined surface is low.

1. Introduction

Recent developments in mechanical industry have fuelled the demand for materials having high toughness, hardness and impact resistance. These materials are difficult to machine with traditional methods. The search for new, lightweight material with greater strength and toughness has led to the development of new generation of materials. Sometimes their properties may create major challenges during machining operations. Wire Electrical discharge machining (WEDM) has evolved from a simple means of making tools and dies to the best alternative of producing micro-scale parts with the highest degree of dimensional accuracy and surface finish quality. WEDM is a nontraditional, thermoelectric process which erodes material from the workpiece using a series of discrete sparks between a work and tool electrode separated by a thin film of dielectric fluid (deionised water). The dielectric is fed continuously to the machining area to flush away the eroded particles [12]. In WEDM cutting, a single-stranded thin wire electrode is fed continuously against the workpiece material through a CNC-controlled guidance system. Fig. 1 [5] shows the schematic representation of the WEDM. Sparks are formed through a sequence of rapid electrical pulses generated by the machine's power supply, thousands of times per second. Each spark forms an ionization channel under extremely high heat and pressure, in which particles flow between the wire electrode and the workpiece, resulting in vaporization of localized sections. The workpiece and the wire are always separated by a controlled gap, which is maintained constantly by the machine [19]. The used wire is collected at the bottom after use and the same cannot be reused again due to dimensional inaccuracies [18]. At the same time, the dielectric cutting fluid cools the material and flushes away particles that have been eroded from it [1]. Nimonic alloys are extensively used for the manufacturing of aeroengine components because of its high specific strength (strength to weight ratio), which is maintained at higher temperature [3]. During prolonged exposure to high temperatures, many metals begin to crack, deform, corrode, fatigue, etc. Nimonic alloys are used for their resistance to corrosion and retention of other mechanical properties at temperatures as high as 1100 °F, depending on the grade [2]. Hard abrasive carbides in the alloy results in high abrasive wear of the cutting tool. Presence of hard abrasive carbides in the microstructure and built up edges produced during machining results in poor machinability. Welding/adhesion of the alloy on the tool during machining, causes severe notching and spalling on the tool face due to the consequent pull-out of the tool material [2,4]. Normal stresses on the tool are

* Corresponding author.
E-mail addresses: amitesh550@yahoo.com (A. Goswami), jatin.tiet@gmail.com (J. Kumar).

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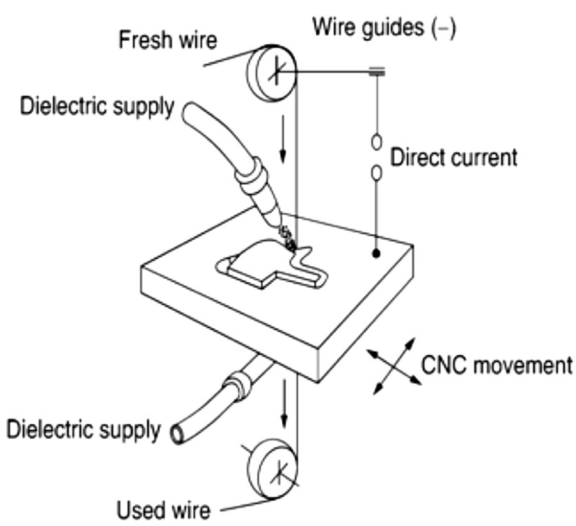

Fig. 1. Schematic representation of the WEDM [5].

roughly twice as high for machining nimonic alloy as for machining steel under the same cutting parameters. This result in breakdown of the cutting tool because of higher stresses applied behind the cutting edge [4]. High temperature is generated at the tool tip due to the poor thermal diffusivity of the Nimonic alloy resulting in tool wear. During machining, high strength is maintained at elevated temperatures, which opposes the plastic deformation needed for chip formation. Production of a tough and continuous chip contributes to the degradation of the cutting by seizure and cratering [3].

A comprehensive literature review has been performed on various aspects of WEDM process and has been summarized in Table 1. It is evident from the literature review; almost no investigation has been performed on the machinability of Nimonic 80A using WEDM process. Moreover the investigations reported on WEDM of the other conventional materials (listed in Table 1) have been focused on parametric optimization of WEDM process with MRR, surface roughness and dimensional deviation as the responses of interest. Very few studies have been reported on investigation of wire wear ratio [20,16]. Also the surface integrity aspects such as surface topography, recast layer and material migration among the electrodes have not been properly investigated in most of the reported studies (Table 1). Hence present study is targeted at investigation of machining characteristics (MRR, WWR) in WEDM of Nimonic 80A alloy along with the surface integrity aspects (surface topography, recast layer and material migration/EDS). The outcome of this study would add to scares database of the machinability of Nimonic 80A alloy and also would be extremely useful for the machinist as the technology charts for WEDM of Nimonic 80A alloy are not easily available.

2. Methodology

The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. The Taguchi method tests pairs of combinations instead of testing all possible combinations. This allows determining the major factors affecting the output, with a minimum amount of experimentation. Analysis of variance on the collected data from the experiments can be used to select new parameter values to optimize the performance characteristic [17]. A cause and effect diagram (Fig. 2) for identifying the potential factors that may affect the machining characteristics (such as MRR) was constructed. From the available literature on WEDM, total six numbers of input parameters were finally selected. In this work, L_{27} orthogonal array with six control factors viz., A, B, C, D, E, F and three interactions viz. $A \times B$, $A \times C$ and $B \times C$ have been studied. The allocation of columns to the input parameters and interactions in the orthogonal array was done using linear graph. Signal to noise ratio was obtained using Minitab 16 software. Higher is better (HB) for MRR and lower is better (LB) for WWR were taken for obtaining optimum machining characteristics.

3. Experimentation

Experiments were performed on Electronica Sprintcut (Electra-Elplus 40A DLX) CNC wire electrical discharge machine to study the material removal rate and wire wear ratio affected by machining process variable at different setting of pulse-on time (T_{on}), pulse-off time (T_{off}), spark gap set voltage (SV) peak current (IP), wire feed (WF) and wire tension (WT). L_{27} orthogonal array (three levels) with six input variables was selected for experimentation. Fig. 3 shows the experimental setup of the WEDM. Tables 2 and 3 show the various process parameters with their values at three levels and L_{27} orthogonal array (with six input variables and three interactions assigned to different columns) respectively. Nimonic 80A (77.05% Ni, 18.39% Cr, 1.92% Ti, 1.05% Al, 0.63% Fe, 0.2% Mn, 0.19% Si) block of thickness 25 mm was used as work material. Specimens (Rectangular) of size 8 mm $\times$ 8 mm $\times$ 25 mm were prepared from the block using brass wire electrode of diameter 0.25 mm (Soft). De-ionized water was used as the dielectric fluid. The total length of each specimen was taken as 34.48 mm $\{32 + 1.84 + (0.16 \times 4)\}$ mm. In this 1.84 mm was the free straight cut and 0.16 mm was taken as left offset on all four sides. Digital stopwatch was used for precise calculation of the time taken (in minutes and seconds). Experiments were conducted thrice to minimize the chances of error. Material removal rate (MRR) was calculated by using the formula:

$$\text{Material removal rate(MRR)} = K \cdot \rho \cdot t \cdot \text{CR} \ \ \text{g/min}. \tag{1}$$

where, K is the kerf (mm), ρ is the density (0.00819 g/mm^3) of the material, t is the thickness (25 mm) of the workpiece and CR is the cutting rate (mm/min).

Wire wear ratio was calculated by using the formula:

$$\text{Wire wear ratio(WWR)} = (\text{IWW} - \text{FWW})/\text{IWW} \tag{2}$$

where,

IWW = initial weight of the wire
FWW = final weight of the wire after machining

Mitutoyo BH.V507 Coordinate Measuring Machine (Fig. 4a) and Mitutoyo digital outside micrometer were used for kerf (Fig. 4b) measurement. Fig. 4c shows the Machining profile of the workpiece. An electronic balance with 0.01 g accuracy was used to measure the weight. In order to minimize the measurement error the average value of three-weight measurements were used. Table 4 shows the various results of the material removal rate and Wire wear ratio, as per designed L_{27} orthogonal array. Minitab 16 software was used for ANOVA. Tables 5 and 6 shows the analysis of variance and F test for material removal rate and Wire wear ratio respectively.

4. Single response optimisation

The Taguchi approach for predicting the mean performance characteristics and determination of confidence intervals for the