Analysis And Optimization Of Process Parameters During Electric Discharge Machining Of Incoloy 800: A Review

Nishant Kumar, P. Sudhakar Rao

Abstract: In recent years, optimization of process parameters has been applied to a variety of machining operations on traditional and non-traditional machines. Non-traditional machining process includes electric discharge machining which is widely used for removal of material as per desired shape. Various types of material being used for machining in EDM which includes Alloy and other conducting materials. One of the materials with considerable importance to be used as work material during EDM process is INCOLOY 800. Inspite of being upgraded to various alloy grades like alloy 800H, alloy 800HT etc., Incoloy 800 needs considerable importance for machining in EDM. It is suitably used material with inevitable properties of heat resistance for service temperature up to 816°C with general application including construction or shaping of equipment requiring strength and stability also. Chromium present in the alloy helps in heat resistance. Presence of Iron provides resistance to internal oxidation. The nickel content present in Incoloy 800 maintains ductile and austenitic structure. Therefore, alloy 800 can be machined easily as per desired shape. Because of its moderate strength, low cost and good resistance to oxidation and carburization at elevated temperatures, alloy 800 and its grades are center of attraction for alloy manufacturing companies. The aim of the proposed study is to review the optimum condition under the influence of various process parameters so that Electric Discharge machining can be optimized when working with Incoloy 800 as a work material.

Index Terms: Electric Discharge Machine (EDM), Surface Roughness (SR), Material Removal Rate (MRR), Tool Wear Rate (TWR), Radial Overcut (RO), Response Surface Methodology (RSM), Ultimate Tensile Strength (UTS), Yield Tensile Strength (YTS).

1. INTRODUCTION

Non-traditional machining processes are widely used for the removal of material having optimum hardness that cannot be machined with the help of traditional processes. Electric Discharge machining technique uses thermoelectric process to remove undesired materials from the work surface by producing electrical sparks between the work piece and the electrode. Electrical spark or thermal energy is used in EDM to for the removal of unwanted material with the help of such discrete sparks in order to create desired shape. Therefore, material hardness has least influence for EDM operations. It removes material by the discharge of electric current between cathode and anode where tool acts as cathode and work material acts as anode. Capacitor bank is used to store electric current, preferably 50 volts and 10 amperes. At the beginning of EDM operation, the electrode and workpiece is being connected with electric source which generates high voltage across the narrow gap between them. Electric field gets created in the insulating dielectric due to presence of such high voltage. This electric field is present in narrow gap between electrode and the work piece which causes conducting particles suspended in the dielectric to concentrate at the points of strongest electrical field. Material removal process starts when the potential difference between the electrode and the work piece is sufficiently high, the dielectric breaks down and a transient spark discharges through the dielectric fluid, which removes sufficient or desired amount of material from the work piece surface. WhileMachining with EDM, the work piece should be electrically conductive, but this limitation does not put an end to it. For one, certain materials, such as super alloy and high-nickel alloy having applications in the aerospace industry. However, the variation of electrode material and slower EDM cycle times serve as the solution to the material issues while considering carbide and standard tool steel. Different types of material being used for machining in EDM which includes Alloy and other conducting materials. One of the materials with considerable importance may be used during EDM process is INCOLOY 800. At elevated temperatures resistance to oxidation and carburization is necessary also aqueous resistance is required which is being provided by nickel content in the alloy. It is generally used in the applications which requires greater resistance to creep and stress rupture, at temperatures above 816°C. Similarly Nickel content enhances its internal structure which helps to provide better machining characteristics of alloy 800. Also because of its low cost and better strength and resistance properties with regard to oxidation and carburization at elevated temperatures, alloy 800 and its grades are a center of attraction for alloy manufacturing companies. Electrical Discharge machining has been used extensively with variety of conducting material at its optimization level. Properties of Incoloy 800 is shown in table.

TABLE 1: *PHYSICAL PROPERTIES OF INCOLOY 800*

Alloy	Form	Condition	UTS (MPa)	YTS (MPa)
Incoloy 800	Sheet	Annealed	586	276

Thermal properties of work material are more pronounced for considering material removal rate rather than its strength and hardness. Composition of INCOLOY 800 as work material is given below:

- *Nishant Kumar is currently pursuing masters' degree program in mechanical engineering from National institute of Technical Teachers training (NITTTR) Sector 26, Chandigarh, India, PH-01722759594. E-mail: nishu180192@gmail.com*
- *P Sudhakar Rao is currently working as assistant Professor in National institute Of Technical Teachers training (NITTTR) Sector 26, Chandigarh, India, PH-01722759617. E-mail: psrao.iitr@gmail.com*

***TABLE 2:** LIMITING COMPOSITION OF INCOLOY 800(%)*

Alloy	Percentage distribution
Nickel	30.0 – 35.0
Chromium	19.0 – 25.0
Iron	39.500 min
Carbon	00.100 max
Manganese	01.500 max
Sulphur	00.015 max
Silicon	01.000 max
Copper	00.750 max
Aluminum	00.15 - 0.60
Titanium	00.15 – 0.60

2 IMPORTANT PARAMETERS USED IN EDM

2.1 Dielectric Medium
Different types of dielectric medium is used in EDM which includes kerosene and deionized water. Dielectric medium is used in the spark zone which maintains oxygen free machining environment. One of the most important features of dielectric medium is having its dielectric resistance so that breakdown cannot occur easily but during the time of collision of electron molecules, it should ionize easily too.

2.2 Gap Voltage
Since electrical spark is generated between electrode and workpiece in EDM therefore, a proper gap is necessary to be maintained which is known as discharge gap. Electrical spark releases huge amount of energy and voltage reaches up to million volts.

2.3 Pulse on Time
It plays an important role in EDM process. The time interval in which particular work is completed is known as pulse on time or the applied time period for voltage pulse.

2.4 Peak Current
It is the amount of power required for maximum current in EDM for each pulse. It also represents discharge current intensity up to maximum value.

2.5 Pulse off Time
It is also known as pulse interval. Pulse off time is the time duration in which there is no current supply when consecutive sparks takes place between electrode and work material. At this time deionization takes place in the dielectric. The time gap in which no spark is generated is known as pulse off time.

2.6 Material Removal Rate:
The material removal rate is one of the most important response parameters which needs to be maximized. It is the amount of material which gets removed while machining. The material removal rate can be calculated from the weight difference before and after machining on the workpiece. Weight difference is generally measured using Weighing machine.

$$MRR = (w1 - w2)/time \qquad - Equation\ 1$$

Where,

w1 = weight of workpiece before machining
w2 = weight of workpiece after machining

2.7 Tool Wear Rate:
The tool wear rate is defined as the amount of material removed from the tool while machining per unit time. The tool wear rate can be calculated from the weight difference before and after machining at the tool. Weight difference is generally measured using Weighing machine.

$$TWR = (w1 - w2)/time \qquad - Equation\ 2$$

Where,

w1 = weight of tool before machining
w2 = weight of tool after machining

2.8 Surface Roughness:
Surface roughness is measured using Surface Roughness Tester

3 LITERATURE SURVEY
Gaikwad et al [1] performed experiment to optimize different parameters for consideration which includes current, pulse off time, pulse on time and fluid pressure in order to minimize TWR and maximize MRR during Electric Discharge machining. Stainless steel 316 grade was taken as work piece material with copper as electrode. Taguchi technique was used to analyze these factors and results were concluded which showed that MRR and TWR were largely affected by pulse off time and current. Copper electrode were used for machining SS 316. George et al [2] presented process optimization on C-C composites as work material using Taguchi Method to determine TWR and MRR. The most effective parameters come out to be gap voltage, peak current and pulse on time which largely effect the MRR and TWR. Ahmet and Ulas [3] observed that MRR, SR and TWR increases with increase in pulse current and pulse duration. The study was done using Taguchi method. The work piece material used as Titanium alloy (Ti– 6Al–4V). Different machining conditions were applied during machining of Titanium alloy. Further experiment revealed that MRR, SR and TWR increases with process parameters while using different electrode material in particular order with pulse duration of 200us. Highest MRR given by graphite electrode which is followed by electrolytic copper and aluminum. Lowest wear rate was also shown by graphite electrode due to its high melting point while best performance was exhibited by aluminum electrode with regard to surface finish. Cheron et al [4] experiment was performed to compare copper and graphite electrode as tool material and results were optimized which concluded that copper electrodes give higher material removal rate as compared with electrode material graphite while using XW42 tool steel as work material for electrical discharge machining. Further his research work verified that copper is best suited for roughing surface while graphite electrode suited for finishing surface. Alidoosti et al [5] performed experiment in order to determine in order to determine EDM characteristics of work material during machining of NiTi alloy. Machining parameters were evaluated for optimum performance in which MRR, SR and EWR was taken as Input parameters. Results were obtained after optimization of parameters showed that increase in pulse current leads to increase in MRR. Further, higher pulse current and large pulse duration increases MRR and at the same time

with increase in pulse duration relative electrode wear ratio decreases. Hessler et al. [6] Experimental investigation was done on surface properties while machining two different nickel-titanium alloys. After investigation done on alloys similar surface characteristics was observed which includes formation of craters and micro cracks while machining these alloys. Material recast layer and crater size also observed to be increased with the increase in pulse duration. Beri et al. [7] investigated the influence of electrode polarity and discharge current while working with Inconel 718 as work material in EDM copper–tungsten powder was used as electrode after being processed significantly. Result showed that maximum MRR and minimum TWR occurs at positive polarity whereas minimum SR was observed at negative polarity. Rajesha et al [8] Studied the machining analysis of Inconel 718 in which copper tool electrode was shaped into hollow tube-like cross section, the most dominant factors which effects MRR are discharge current and duty factor. Input parameters discharge current, medium flushing pressure, sensitivity control and gap control when helped in obtaining better surface finish when kept at low values. Above result were analyzed using Taguchi design of experiment. Bharti et al [9] Taguchi methodology was applied in showed that with increase in pulse duration MRR and SR were observed to increase and as well with discharge current. Experiment correlates different process parameters and performance characteristics during die sinking EDM of Inconel 718. Kang and Kim [10] Investigation was done using Hastelloy X which is based on nickel-based super alloy as work material, carbon deposition was observed on tool surface on increasing pulse-on time which increases material removal rate. Therefore, it has been concluded that MRR also leads to deposition of carbon on work piece surface. Lee and Tai [11] Process optimization and analysis was carried out which revealed that with increase in pulse current and pulse on duration, the surface roughness also increases. Further increase in pulse duration effected by both the induced stress and average white layer thickness. As determined from results, EDM parameters are also related to crack formation. Ghewade and Nipanikar [12] Investigation was done using Inconel 718 and copper electrode during machining in order to obtain the machining characteristics using Taguchi Methodology. Results revealed that MRR increased by peak current whereas tool wear rate was affected by pulse-on time and duty cycle. Results also revealed that material removal rate was mainly affected by peak current and gap voltage. Peak current also showed some effect on half taper angel but gap voltage was again observed to be less effective factor while considering half taper angle. Further it has also been observed that peak current and gap voltage has very less effect on electrode wear rate. Muthukumar et al [13] mathematical model were presented while machining of Incoloy 800 as work material to determine radial overcut in electrical discharge machining. Experiments concluded radial overcut can be minimized by lowering the values for current and voltage. Response Surface methodology was adopted to determine at optimum results and analysis were performed using ANNOVA. Further results also clarified that pulse off time has lower influence than voltage for obtaining the optimized values. Paul et al [14] machining response were studied on MRR using Inconel 800 as work material with copper tool as electrode for an EDM process. Various operating parameters Pulse on time. Pulse off time and pulsed current were set up for the experimentation. Response surface methodology were used for generating the model for MRR using above given parameters. Analysis were made using Regression analysis procedure in order to determine the relationship between input-output parameters. Finally, results were obtained which clearly indicated that in order to increase the spark energy across the electrode gap, current value need to be increased which also increases MRR value. Kuppan et al [15] Investigation was done using Inconel 718 on EDM. Drilling was done on work material which revealed that peak current has to be increased in order to ensure rise in MRR. Other parameters which also shows rise in MRR are duty factor and electrode speed. Average surface roughness was also observed to increase on increasing the values for peak current and pulse on time. Whereas increase in electrode speed also leads to further rise in surface roughness. RSM techniques has been used by author and mathematical models were developed to generate response of material removal rate and surface roughness. Aveek et al [16] concluded based on experimental investigation and analyzed that EDM characteristic of Inconel 825 which showed that in order to obtain higher material removal rate, peak current and pulse on time should be increased during electric discharge machining of Inconel 825 as work material but better surface finish of machined surface has been obtained when peak current and pulse on time kept at lower level. Above observations were obtained from experimental results. Rajyalakshmi and Ramaiah [17] Experiments were performed using Taguchi Gray Analysis using Inconel 825 as work material. In order to increase MRR and decrease SR, some of the parameters which have major effect includes Pulse duration, dielectric flow rate, servo feed and pulse-off time. Further considerable effect includes corner servo voltage, wire feed rate, spark gap voltage, and wire tension. Finally, it has been concluded that Taguchi Gray Analysis is most suitable for wire cut EDM during machining of Inconel 825. Optimum values were obtained for wire EDM using method of grey relational analysis with Inconel 825 gives 105 µs pulse on time, 30 V spark gap voltage, 50 µs pulse off time. Karunakaran and Chandrasekaran [18] Electric discharge machining was carried out using Inconel 800 as work material and machinability results were obtained after optimization. The average values of various output parameters were obtained as 0.27603 g/min of MRR, 1.71 µm SR and .00255 g/min of TWR when setting the optimum or optimized values as 5 A of peak current, 8 µs pulse on time and 4 µs pulse off time. Mahendra and Deepak [19] studied the effect dielectric mixed with powder in EDM which has been analyzed during machining of Inconel 718 with copper electrode having 6 mm diameter. Dielectric used is Kerosene oil mixed with SiC, aluminium oxide and graphite powder mixed as per standard in kerosene. Effect of various parameters which includes peak current, pulse on time, different dielectric medium and duty cycle were observed on MRR and TWR. Optimum machining condition was selected for Inconel 718 as work material. Experiments showed that the addition of powder in kerosene leads to high MRR and minimum TWR. Results were generalized using Taguchi Method. Analysis was done using Analysis of variance method for process optimization considering MRR and TWR.

4 CONCLUSIONS

Since machining is greatly influenced by MRR, TWR and SR. Therefore, Pulse on time, voltage, current and type of dielectric medium will be taken as input parameters for optimization purpose. Pulse on time may be most effective parameter for obtaining maximum MRR. Type of dielectric fluid may influence Tool wear rate and heat removal. Current may affect the penetration power. Taguchi methodology may be adopted for process optimization.

(a) During process of optimization, most influential parameters will be considered so as to determine SR, MRR and TWR which is largely influenced by current, pulse on time and voltage.
(b) Various studies have been conducted on varieties of steel grades and super alloys. Nickel titanium alloys and super alloys (Inconel and Incoloy grades) are most preferred as per recent studies and research shown in the literature review.
(c) MRR may increase with pulse on time but voltage influence is more as compared with pulse off time. Surface roughness may increase with rise in pulse duration.
(d) Powder mixed dielectric fluid can be used for process optimization in EDM

REFERENCES

[1] Abhishek Gaikwad, Amit Tiwari, Amit Kumar and Dhananjay Singh, “Effect of EDM parameters in obtaining maximum MRR and minimum EWR by machining SS 316 using Copper electrode” International Journal of Mechanical Engineering and Technology (IJMET) ISSN 0976.
[2] PP.M. George, B.K. Rahunath, L.M. Manocha and Ashish M. Warrier, “EDM machining of carbon composite a Taguchi approach”, Journal of Material Processing Technology 145(2004) 66-71.
[3] Ahmet Hascalık and UlasCaydas, “Electrical discharge machining of Titanium alloy (Ti– 6Al–4V)” Applied Surface Science 253 (2007) 9007–9016
[4] C.H. Cheron, J.A Ghani, Y.K. Seong and C.Y. Swee,“Copper and graphite electrode performance in electrode discharge machining of XW42 tool steel” journal of materials processing technology (2008).
[5] Ali Alidoosti, Ali Ghafari-Nazari, Fathollah Moztarzadeh, Newsha Jalali, Sina Moztarzadeh and Masoud MozafariJournal of Intelligent Material Systems and Structures 2013 24: 1546.
[6] Hesser-Wyser, A. Bobard , F., Demellayer, R., Perez, R., Flukiger, Cusanelli, G, 2004. Microstructure at submicron scale of white layer produced by EDM technique, Journal of Materials Processing Technology 149, 289-295
[7] Beri, N.; Pungotra, H.; Kumar, A. To study the effect of polarity and current during electric discharge machining of Inconel 718 with CuW powder metallurgy electrode.In Proceedings of the National Conference on Trends and Advances in Mechanical Engineering, YMCA University of Science & Technology, Faridabad, Oct 19–20, 2012.
[8] Rajesha, S.; Sharma, A.K.; Kumar, P. On electro discharge machining of Inconel 718 with hollow tool. Journal of Materials Engineering and Performance 2012, 21 (6),882–891.
[9] Bharti, S.P.; Maheshwari, S.; Sharma, C. Experimental investigation of Inconel 718 during die-sinking Electric discharge machining. International Journal of Engineering Science and Technology 2010, 2 (11), 6464–6473.
[10] Kang, S.H.; Kim, D.E. Investigation of EDM characteristics of nickel based heat resistant alloy. KSME International Journal 2003, 17 (10), 1475–1484.
[11] H.T. Lee, T.Y. Tai. Relationship between EDM parameters and surface crack formation Journal of Materials Processing Technology 142 (2003) 676–683.
[12] Ghewade, D.V.; Nipanikar, S.R. Experimental study of electro discharge machining for Inconel material. Journal of Engineering Research and Studies 2011, 2 (2), 107–112.
[13] Muthukumar, V., Rajesh, N., Venkatasamy, R., Sureshbabu, A., & Senthilkumar, N. (2014). Mathematical Modeling for Radial Overcut on Electrical Discharge Machining of Incoloy 800 by Response Surface Methodology. Procedia Materials Science, 6, 1674–1682.
[14] TR. Paul, H.Majumder, V. Dey and P. Dutta Study the Effect of Material Removal Rate in Die-sinking EDM for Inconel 800 using Response Surface Methodology.Journal of Material Science and Mechanical Engineering (JMSME) April-June, 2015 pp. 27-31.
[15] Kuppan, P.; Rajadurai, A.; Narayanan, S. Influence of EDM process parameters in deep hole drilling of Inconel 718.International Journal Advanced Manufacturing Technology 2008, 38, 74–84.
[16] Aveek Mohanty, Gangadharudu Talla, and S. Gangopadhyay Experimental Investigation and Analysis of EDM Characteristics of Inconel 825.Materials and Manufacturing Processes, 29: 540–549, 2014.
[17] Rajyalakshmi, G.; Ramaiah, P.V. Multiple process parameter optimization of wire electrical discharge machining on Inconel 825 using Taguchi grey relational analysis. International Journal of Advanced Manufacturing Technology 2013, 69 (5–8), 1249–1262.
[18] Karunakaran and M. Chandrasekaran. machinability study on die shrinking EDM of Inconel 800 with electrolyte copper elctrode. Arpn Journal of Engineering and Applied Sciences. 2017.
[19] Mahendra G. Rathi, Deepak V. Mane Study on Effect of Powder Mixed dielectric in EDM of Inconel 718, International Journal of Scientific and Research Publications, Volume 4, Issue 11, November 2014, pp1-7.