Machining of Inconel 718 Alloy using EDM-A Review

Vrushali Bunde [a],
[a]P.G Student, Production Engineering,
Government College of Engineering,
Amravati, Maharashtra

Dr. R. S. Dalu[b]
[b]Head of the Department ,
Mechanical Engineering,
Government College of Engineering,
Amravati, Maharashtra

Abstract: **EDM is the process of machining hard metals which are cannot be machined using conventional machining process. This method was developed in the late 1940s, has been accepted worldwide as a standard process in manufacturing of forming tools. EDM find a wide application in the machining of hard metals. EDM is mainly used in industries like prototype production, coinage die making and in small hole drilling.Inconel718 is a high nickel content alloy. Inconel718 was developed to meet the need for a nickel-base alloy suitable for manufacture into complex shaped components subject to a combination of high temperature, high stress, and high temperature corrosion. The inconel718 material is mainly used in aerospace, missile and marine industries. Due to their high strength these alloys are difficult to machine conventionally. For this reasons another alternative for their machining is EDM. The aim of this work is to give a review related to machining of Inconel 718 alloy on EDM which is carried out till now.**

Keywords - Electric Discharge Machine, Inconel 718 alloy, Process parameters, machining characteristics, electrode material.

1. INTRODUCTION

At the present Electrical discharge machining is widespread technique used in industry for high precision machining for all types of conductive materials such as metals, metallic alloys, ceramic materials, super alloys etc. of whatever the intensity of hardness . EDM is used in the industries like aeronautics, automobiles, nuclear reactors, missiles, turbines etc. materials like high strength temperature resistant alloys which have higher strength, corrosion resistance, toughness and other diverse properties. The major advantage of EDM is that the machining process enables us to obtain components with desired shape and closer dimensional tolerance in a shorter time, compared to that in case of traditional machining process . The selection of EDM parameters for optimum output characteristics requires large experimental work due to this reason experiment which consists of checking the surface integrity of Inconel 718 alloy is only carried out till date using copper as electrode. A super alloy, or high-performance alloy, is an alloy that exhibits several key characteristics, excellent mechanical strength, resistance to thermal creep deformation, good surface stability and resistance to corrosion or oxidation. The crystal structure is typically face-centred cubic austenitic. Super alloys are the alloys which posses comparatively higher mechanical and thermal strength in comparison to individual metals. These properties of the super alloys make them eligible for the purpose where in high strength to weight ratio of a material is expected. Due to this reason machining of Inconel 718 alloy on conventional machining processes is a difficult task. Inconel 718 alloy is one of the super alloys which find its application in the areas such as Gas turbine engines, Compounding of industrial furnace, Nuclear power plant, Aerospace component, Submarine and Chemical industries, Heat exchangers, Food processing equipments, Petrochemical plants etc.

Difficulties faced in machining of Inconel 718 alloy-
When it comes to machining of the Inconel 718 alloy it is difficult to machine it on conventional machining processes due to the following reasons

1. During machining high strength and hot hardness of nickel based alloy causes deformation of cutting tool.
2. INCONEL 718 alloy gets rapid work hardening during machining due to the austenite matrix, this is the reason for tool wear at depth of cut line.
3. Localization of shear stress and formation of abrasive saw tooth edge result in notching of cutting tool. High dynamic shear strength is the reason behind notching of cutting tool.
4. The work piece get welded with the cutting tool edge resulting unstable build up edge formation ,which hamper the surface roughness of work piece during machining.
5. INCONEL 718 alloy has the tendency to react with cutting tool material at elevated temperature causing tool wear.
6. Presence of the abrasive particle in the microstructure results in rapid tool wear due to different wear mechanism. The combined property of mechanical strength and high temperature resistance results in poor machinability of Inconel 718 alloy.

2. EDM PROCESS PARAMETERS

The process parameters which will influence the experiment of optimizing while machining of the Nimonic alloy are listed below

i) Discharge current - It points out the different levels of power that can be supplied by the generator of the EDM

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

machine and represents the mean value of the discharge current intensity.
ii) Pulse-on time - It is the duration of time (μs) the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this pulse-on time. This energy is controlled by the discharge current and the duration of the pulse-on time.
iii) Pulse-off time - It is the duration of time (μs) between the two successive sparks (pulse-on time). This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut. Thus, if the off-time is too short, it will cause sparks to be unstable.
iv) Duty cycle - It is a percentage of the pulse-on time relative to the total cycle time. This parameter is calculated by dividing the pulse-on time by the total cycle time (pulse-on time plus pulse-off time). The result is multiplied by 100 for the percentage of efficiency, called duty cycle.

3. EDM MACHINING CHARACTERISTICS

The effectiveness of EDM process is evaluated in terms of its machining characteristics. The short product development cycles and growing cost pressures have forced the die and mould making industries to increase the EDM efficiency. The EDM efficiency is measured in terms of its machining characteristics viz. material removal rate, surface roughness and tool wear rate. The most important machining characteristics considered in the present work are:
i) Surface Roughness (R_a): Surface finish is an essential requirement in determining the surface quality of a product. The average surface roughness is the integral absolute value of the height of the roughness profile over the evaluation length (L) and was represented by the equation given below.

$$R_a = \frac{1}{L}\int_0^L |Y(x)dx|$$

Where 'L' is the length taken for observation and 'Y' is the ordinate of the profile curve.

ii) Material removal rate (MRR): Material removal rate is a desirable characteristic and it should be as high as possible to give least machine cycle time leading to increased productivity. Material removal is the difference of weight of work-piece before machining and after machining. It is calculated by the formula as given below.

$$MRR = \frac{W_i - W_f}{\rho_w \ t} \quad / \text{min}$$

Where, W_i is the initial weight of work-piece in g; W_f is the final weight of work-piece after machining in g; t is the machining time in minutes and ρ_w is the density of work piece material.

iii) Tool Wear Rate (TWR): Tool wear rate is the difference of electrode weight before and after machining and is expressed as:

$$TWR = \frac{E_i - E_f}{\rho_e \ t} \quad \text{mm}^3/\text{min}$$

Where, E_i is the initial weight of electrode in g; E_f is the final weight of electrode after machining in g; t is the machining time in minutes and ρ_e is the density of electrode material.

4. RESEARCH WORK ON MACHINING OF INCONEL 718 ALLOY ON EDM

The area of early research was focused on the study of fatigue life.Jeelani and Collons [3] investigated on the fatigue life of Inconel 718 and concluded that the fatigue life of the specimens machined using EDM decreased slightly as compared with that of the virgin material. The micro-hardness and roughness of the machined surfaces increased marginally, producing a hard recast layer.
Later the EDM process was used to study the response parameters such as MRR, EWR, SR and recast layer. Hastelloy-X was investigated under the various EDM conditions and analyzed in terms of surface integrity by Kang and Kim [4]. The parameter which was varied in the study was pulse on-time. The results demonstrated that MRR and EWR behaved nonlinearly with respect to the pulse duration, whereas the morphological and metallurgical features showed rather a constant trend of change by the pulse duration. The pulse-on time also affected the number of micro-cracks and the thickness of AMZ (altered material zone).
Wang et al. [5] explored the feasibility of removing the recast layer (RCL) using etching and mechanical grinding for Ni-based superalloy materials by means of EDM. The experiment was conducted using L18 orthogonal arrays and the results proved that a positive polarity process could create a thicker recast layer than negative polarity. L9 orthogonal arrays were also used in the experiments and the results proved that the corrosive made up of phosphoric acid and hydrochloric acid under proper temperature could significantly enhance the recast layer removal rate for Inconel 718 alloy. The micro-hardness test of recast layer and base material proved that corrosion using phosphoric acid and hydrochloric acid could only damage the structure of the recast layer and that base material hardness would not be damaged at all.
Rajesh et al. [6] investigated the surface integrity evaluation issues while machining Inconel 718 through EDM. The distinctive morphology of the machined surface (recast layer) was due the enormous amount of heat discharge during sparking that causes melting and vaporization of the material, followed by swift cooling.
Bharti et al. [7] investigated the machining characteristics of Inconel 718 during die-sinking electric discharge machining process with copper as tool electrode. Discharge current and pulse on-time were identified as common influencing parameters for MRR, SR and TWR. Duty cycle and tool electrode lift time were found the least influential parameters.

Rajesha et al. [8] planned the experiments as per Taguchi's L18 orthogonal array and trials were carried out in a CNC-EDM machine with 99.9 % pure copper tool having tubular section; commercial grade kerosene was used as dielectric fluid. The effect of process parameters pulse current, pulse on-time, gap control and flushing pressure on MRR was investigated while machining Inconel 718. It was concluded that the pulse current is the most significant parameter in the process, followed by pulse on-time and pulse off-time.

Kristian [9] in his study on IN 100mod Ni-base alloy, used two different qualities of electrode Poco AF5 and Poco EDM3 and tested in a 23 factorial test with two levels of discharge current and pulse duration. The results demonstrated that EDM3 graphite performs very well giving significantly higher MRR than AF5, with acceptable relative electrode wear. The AF5 gives significantly lower electrode wear and MRR.

Hewidy et al. [10] in their work highlighted mathematical models for correlating the inter-relationships of various Wire-EDM machining parameters of Inconel 601 material such as: peak current, duty factor, wire tension and water pressure on the MRR, wear ratio and SR. The process has proved its adequacy to machine the material under acceptable volumetric material removal rate of 8 mm3/min and surface finish (Ra) less than 1 µm. The volumetric metal removal rate and surface roughness both increases with increase in peak current has been established based on the response surface methodology (RSM).

Newton et al. [11] conducted an experimental investigation to determine the main wire-EDM parameters which contribute to recast layer formation in Inconel 718. It was established that average recast layer thickness increased primarily with energy per spark, peak discharge current, and pulse duration. The range of parameters tested, the recast layer was observed to be between 5 and 9 µm in average thickness, which was highly variable in nature. The recast material was found to possess in-plane tensile residual stresses, as well as lower hardness and elastic modulus than the bulk material.

Ramakrishnan and Karunamoorthy [12] described the development of ANN models and the multi-response optimization technique to predict and select the best cutting parameters for the wire electro-discharge machining (WEDM) process of Inconel 718.

Muthu Kumar et al. [14] demonstrated optimization of WEDM process parameters of Incoloy 800 super alloy with multiple performance characteristics and concluded that the Grey-Taguchi Method is most ideal and suitable for the parametric optimization of the Wire-Cut EDM process, when using the multiple performance characteristics such as MRR, SR and kerf width.

Bai [15] investigated the effects of the electrical discharge alloying (EDA) process with Al-Mo composite electrode on improving the high temperature oxidation resistance of the Ni-based superalloy Haynes 230. The oxidation resistance of the specimen alloyed with positive electrode polarity is better than that of the unalloyed superalloy, and the effective temperature of oxidation resistance of the alloyed layer was achieved to 1100 ºC. Conversely, the oxidation resistance of the other EDA specimen alloyed with negative electrode polarity was even worse than that of the unalloyed superalloy.

In their previous work Bai et al. [16] presented the EDA process of the superalloy Haynes 230 with aluminum and molybdenum, and the alloying effects of different EDA conditions have also been determined and compared. Suitable experiment conditions can help to form an aluminum-rich layer on the surface of the superalloy.

Klocke et al. [17] investigated the influence of powder suspended dielectrics on the recast layer of Inconel 718 EDMed surface. They reported that a physical property of the powder additives plays an important role in changing the recast layer composition and morphology.

Kumar et al. [18] realized the potential of graphite powder as additive in enhancing machining capabilities of Additive mixed EDM on Inconel 718 and found that addition of graphite powder enhances machining rate appreciably. Machining rate is improved by 26.85% with 12g/l of fine graphite at best parametric setting.

Prabhu and Vinayagam [19] carried out the EDM process on Inconel 825 with carbon nano tube (CNT) mixed with dielectric fluid for analyzing the surface characteristics. Atomic force microscope (AFM) analysis using CNT improves the surface characteristics like surface morphology, surface roughness and micro cracks from micro level to nano level.

Kuppan et al. [20] carried out experimental investigation of small deep hole drilling of Inconel 718 using the EDM process and revealed that MRR is more influenced by peak current, duty factor and electrode rotation, whereas depth average surface roughness is strongly influenced by peak current and pulse on-time. To achieve better surface finish low value of pulse on-time to be selected. An increase in electrode speed leads to increase in MRR whereas depth average surface roughness decreases to minimum value (between 200 to 300 rpm) and then increases. Better surface integrity was achieved by moderate values of amperage.

Bozdana et al. [21] presented a comparative experimental study on machining and surface characteristics of through and blind holes (Ø1 mm) produced on aerospace alloys of Ti-6Al-4V and Inconel 718 by fast hole rotary EDM process using tubular hollow copper and brass electrodes. It was revealed that the achievement of desirable MRR and EW values and acceptable topography of machined surfaces were dependent upon the appropriate selection of tool electrode material and the choice of making through/blind hole.

Yilmaz and Okka [22] presented a comparative experimental investigation of EDM fast hole drilling of Inconel 718 and Ti-6Al-4V by using single and multi-channel tubular electrodes made of brass and copper materials. The experimental results revealed that the single-channel electrode has comparatively better material removal rates and lower electrode wear ratio and multi-channel electrodes produce better surfaces than single channel electrodes for both aerospace alloys. Micro-structural changes while drilling operations for both types of electrodes result in an annealing effect on Inconel 718

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

and a tempering effect on Ti-6Al-4V alloy. In addition, multi-channel electrodes produce comparatively lower hardness values.

5. RESULTS AND DISCUSSIONS

After reviewing the literature related to machining of Inconel 718 alloy on EDM it is clear that the surface roughness is the key parameter along with other machining parameters like material removal rate and tool wear rate which are needed to be looked after for optimum machining results in the machining of Inconel 718 alloy. Other than these factors tool material is also an important factor to be considered and very less published work is available in this regard. For the purpose of the above research works various method to design the experiments are mentioned which are the Taguchi Method and the response surface methodology. It is observed that though the RSM gives the results with a higher accuracy level and taking in consideration various input factors at various points during the experiments still the result obtained from Taguchi method are not out of the desired confidence level. Also the Taguchi method is easier and gives the results near to the RSM in the experiments done over the EDM of nickel based alloy.

6. RESEARCH GAPS AND PROBLEMS

As discussed the published work consisting of machining of the Inconel 718 alloy taking in to consideration electrode material is not available. Machining of such high strength alloy is done over the conventional machining processes but with difficulties. The EDM process is helpful for the purpose of machining such high strength alloys but very less research work is carried out in this regard. In EDM process other important factors can be considered for improving the machining of super alloys like suspension of powders in the dielectric can be done in order to obtain good surface finish and which also affects the material removal rate. Still much more work is to be carried over the machining of Inconel 718 alloy on the EDM.

7. CONCLUSION

This article presents a review of the work carried on the machining of the Inconel 718 alloy on the EDM so far. Various optimization techniques like the Taguchi method and the RSM are reviewed which are concluded to give better results in the machining of the Nimonic alloy. Some of the key areas where in further research can be done in order to optimize the machining of inconel 718 on the EDM are also highlighted this includes majorly two important aspects these are the use of composite electrode in the machining of the Inconel 718 alloy and the use of powder suspended in the dielectric for the purpose of improving the surface finish and the material removal rate. So far the use of only Gr, Al, SiC and B4C powders has been reported other material powders can also be tried. Also the mechanism of the material transfer from the electrode to the work piece via the particles used in the dielectric can be studied for the improvement of surface finish.

8. REFERENCES

[1] Lazarenko B.R.,“To invert the effect of wear on electric power contacts”, Dissertation of the All-Union Institute for Electro Technique in Moscow/CCCP, Russian, 1943.
[2] Abu Zeid O.A.,“On the effect of electro discharge machining parameters on the fatigue life of AISI D6 tool steel”, Journal of Materials Processing Technology, Vol. 68, No. 1, pp. 27-32, 1997.
[3] Jeelani S., Collins M.R.,“Effect of electric discharge machining on the fatigue life of Inconel 718”, International Journal of Fatigue, Vol. 10(2), pp. 121-126, 1988.
[4] Kang S.H., Kim D.E.,“Investigation of EDM Characteristics of Nickel-based Heat Resistant Alloy”, KSME International Journal, Vol. 17(10), pp. 1475-1484, 2003.
[5] Wang C.C., Chow H.M., Yang L.D., Lu C.T.,“Recast layer removal after electrical discharge machining via Taguchi analysis: A feasibility study”, Journal of Materials Processing Technology, Vol. 209, pp. 4134-4140, 2009.
[6] Rajesh S., Patnaik P.K., Sharma A.K., Kumar P.,“Surface integrity evaluation of electro discharge machined Inconel 718”, Proceedings of the 3rd International 24th AIMTDR Conference, pp. 259-264, 2010.
[7] Bharti P.S., Maheshwari S., Sharma C.,“Experimental investigation of Inconel 718 during die-sinking electric discharge machining”, International Journal of Engineering Science and Technology, Vol. 2(11), pp. 6464-6473, 2010.
[8] Rajesha S., Sharma A.K., Kumar P.,“An approach to optimisation of process parameters while EDMing Inconel 718 using Taguchi’s orthogonal array”, International Journal of Production Quality Engineering, Vol. 2(1), pp. 19-26, 2011.
[9] Kristen L.A.,“Performance of two graphite electrode qualitied in EDM of seal slots in a jet engine turbine vane”, Journal of Materials Processing Technology, Vol. 149, pp. 152-156, 2004.
[10] Hewidy M.S., El-Taweel T.A., El-Safty M.F.,“Modelling the machining parameters of wire electrical discharge machining of Inconel 601 using RSM”, Journal of Material Processing Technology, Vol. 169, pp. 328-336, 2005.
[11] Newton T.R., Melkote S.N., Watkins T.R., Trejo R.M., Reister L.,“Investigation of the effect of process parameters on the formation and characteristics of recast layer in wire-EDM of Inconel 718”, Materials science and engineering, Vol. (A) 513-514, pp. 208-215, 2009.
[12] Ramakrishnan R., Karunamoorthy L.,“Modeling and multi-response optimization of Inconel 718 on machining of CNCWEDM process”, Journal of Material Processing Technology, Vol. 207 (1-3), pp. 343-349, 2008.
[13] Aspinwall D.K., Soo S.L., Berrisford, A.E., Walder G., “Workpiece surface roughness and integrity after WEDM of Ti-6Al-4V and Inconel 718 using damage generator technology”, Annals of CIRP, Manufactung Technology, Vol. 57, pp. 187-190, 2008.
[14] Muthu Kumar V., Suresh Babu A., Venkataswamy R., Raajenthiren M.,“Optimization of the WEDM parameters on machining Incoloy 800 super alloy with multiple quality characteristics”, International Journal of Engineering Science and Technolology, Vol. 2 (6), pp. 1538-1547, 2010.
[15] Bai C.Y.,“Effect of electric discharge surface modification of superalloy Haynes 230 with aluminum and molybdenum on oxidation behavior”, Corrosion Science, Vol. 49, pp. 3889-3904, 2007.
[16] Bai C.Y., Koo C.H., Wang C.C.,“Electrical discharge surface alloying of supealloy Haynes 230 with aluminum and molybdenum”, Material Transactions, Vol. 45, pp. 2878-2885, 2004.

[17] Klocke F., Lung D., Antonoglou G., Thomaidis D.,“The effect of powder suspended dielectrics on the thermal influenced zone by electro discharge machining with small discharge energies”, Journal of Material Processing Technology, Vol. 149, pp.191-197, 2004.
[18] Kumar A., Maheshwari S., Sharma C., Beri N.,“Realizining potential of graphite powder in enhancing machining in AEDM of nickel based super alloy 718”, Proceeding of International. Conference on Advances in Mechanical Engineering, pp. 50-53, 2010.
[19] Prabhu S., Vinayagam B.K.,“AFM surface investigation of Inconel 825 with multi wall carbon nano tube in electric discharge machining process using Taguchi analysis”, Archives of Civil and Mechanical Engineering, Vol. XI (1), pp. 149-170.
[20] Kuppan P., Rajadurai A. and Narayanan, (2008), “Influence of EDM process parameters in deep hole drilling of Inconel 718”, International Journal of Advanced Manufacturing Technology,. Vol. 38, pp. 74-84, 2011.
[21] Bozdana A.T., Yilmaz O., Okka M.A., Filiz I.H.,“A comparative experimental study on fast hole EDM of Inconel 718 and Ti-6Al-4V”, 5th International Conference and Exhibition on design and production of Machines and dies/moulds, pp.18-21, 2009.
[22] Yilmaz O., Okka M.A.,“Effect of single and multi-channel electrodes application on EDM fast hole drilling performance”, International Journal of Advanced Manufacturing Technology, Vol. 51, pp. 185-194, 2010.
[23] Arun Muthu B., Karthik K.M., Soundararajan, R., Palanisamy A.,“Characteristics of Magnetic Force-Assisted Electric Discharge Machining on Inconel 800”, Sixth International Conference on “Precision, Meso, Micro and Nano Engineering”, COPEN 6, pp. G7-G11, 2009.
[24] Asokan T., Reddy S.S., Costa P.D.E.,“Electrical discharge drilling of titanium alloys for aerospace applications”, Proceeding19th AIMTDR Conf., IIT Madras, Chennai, pp. 161-165, 2000.
[25] Pradhan B.B., Masanta M., Sarkar B.R., Bhattacharyya B.,“Investigation of electrodischarge micro-machining of titanium super alloy”, International Journal of Advanced Manufacturing Technology, 2008.