IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X.
PP 56-61
www.iosrjournals.org

Investigation of Electric Discharge Machining of Inconel 718 Using Special Graphite Electrode

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***Abstract**: Electric Discharge Machining is a non-conventional machining process, used to machining difficult to machine materials. The major problem faced while doing EDM is high tool wear rate, end wear, corner wear , surface roughness and low material removal rate,. In this research work experimental investigations have been made to find the machining characteristics of high density ultra fine graphite and Inconel 718 superalloy. The present paper presents the effects of peak current, pulse on-time(Ton) and duty cycle on the output parameters like Material Removal Rate(MMR, End Wear and Surface Roughness(SR).*

***Keywords:** Electrical Discharge Machining (EDM), End Wear, Material Removal Rate (MRR), Surface Roughness(SR)*

I. INTRODUCTION

The Electric Discharge Machining(EDM) is by far the most widely used machining process among the non-traditional machining methods. The EDM involves a controlled erosion of electrically conductive materials by the initiation of rapid and repetitive spark between the electrode tool and workpiece, separated by a small gap. This spark gap is either flooded or immersed under the dielectric fluid. The spark discharge is produced by controlled pulsing of direct current between the workpiece and the tool. The dielectric fluid in the spark gap is ionized under the pulsed application of direct current, thus enabling a spark discharge to pass between the tool and the workpiece. Each spark produces enough heat to melt and vaporize a tiny volume of the workpiece material, leaving a small crater on its surface. The energy contained in each spark is discrete and it can be controlled so that the material removal rate and surface finish can be predicted [1].The EDM process was developed for machining difficult to machine material like carbides, hard nonferrous alloys, tool and die steels and superalloys. EDM can be applied to all electrically conducting metal and alloys irrespective of its melting point, toughness, hardness and brittleness[2]. Fragile and slender workpieces can be machined without distortion. It is also successfully employed for producing intricate and irregular shaped profiles common in tool rooms. Now a days the every industry from tool room to big companies in every filed like tool and die, automobile, aerospace and electronics industries is using EDM. EDM chief applications are in the manufacture and reconditioning of press tool and forging dies as well as moulds for injection moulding.

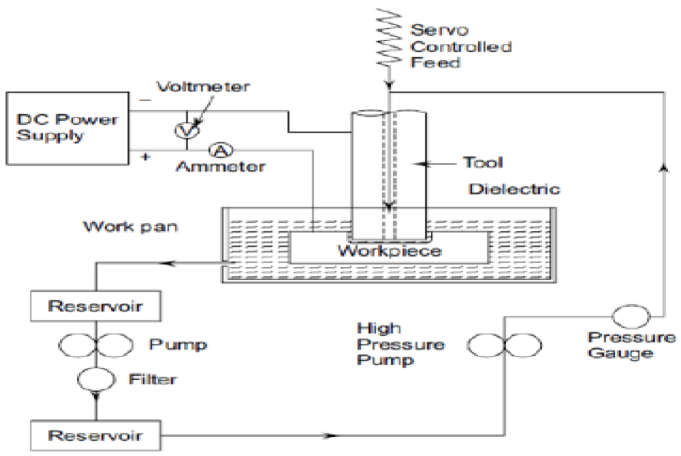

Fig 1: Set up of EDM. [3]

Bharti et al. [4] reported that with copper electrode MRR, SR and TWR are mainly influenced by discharge current and pulse on- time. Least influential parameters are duty cycle and tool lift time while EDMing of Inconel 718.Rajesha et al. [5] reported the effect of discharge current, on-time, flushing pressure and tool gap on MRR and found discharge current as the most influential parameter followed by pulse on-time while EDMing of Inconel 718 using tubular pure copper electrode. Kristian [6] reported the effect of various input parameters on MRR and electrode wear using two different POCO grade electrodes AF5 and C3 on Inconel 100. Higher MRR and acceptable electrode wear was found for C3 electrode. Lower MRR and electrode wear was reported for AF5 electrode. Kuppan et al. [7] reported that while making deep hole in Inconel 718, peak current, rotation of electrode and duty factor mainly influence the MMR. Pulse on-time and peak current mainly influence surface roughness. For good surface finish lower values of discharge current and pulse on-time are recommended. Bozdana et al. [8] reported a comparative study of the effect of tubular hollow brass and copper electrode on various machining and surface characteristics on Ti-6Al-4V and Inconel 718. The desired material removal, electrode wear and topography of machined surface depend on proper selection to make through and blind hole and selection of electrode material. The brass electrode provide better MRR than copper electrode for machining of through and blind hole on Ti-6Al-4V and Inconel 718. Yilmaz et al. [9] reported a comparative study of the effect of single channel and multi channel tubular electrodes made of copper and brass on Ti-6Al-4V and Inconel 718. Annealing effect is observed on Inconel 718 and tempering effect on Ti-6Al-4V. Lower hardness values were absorbed in multi channel electrode. Better surfaces were achieved for both the aerospace alloys by multi channel electrode than single channel electrode. Better MRR and low EW ratio were obtained by single channel electrode and better surfaces were obtained by multi channel electrode. Muthu et al. [10] reported the machining characteristics like MMR, EWR and SR on Inconel 800 by conventional and magnetic assisted EDM. Higher MRR rate and good quality surface is obtained with a magnetic force assisted EDM.

II. EXPERIMENTAL PROCEDURE AND PARAMETERS

The experiments have been conducted on a numerically controlled (NC) die-sinking EDM Machine of Electronica India make. Sparkonix machine is servo controlled by an NC code programming and the servo control feedback is dependent on the gap voltage between the electrode and workpiece. Graphite tool ELLOR +50 having high density ultra fine grain of size <5 µm was bought from Mesen Kunshan Co. Ltd. Copper was then gas pressure infiltrated into porous graphite electrode. In gas pressure infiltration, pores of preform are infiltrated by molten matrix material under the influence of high gas pressure to prepare composite material. Graphite electrode is having isotropic grain structure resulting in very high strength, good wear resistance and finer surface finishes. This electrode is recommended for application which requires taper cavities, blind cavities requiring sharp corners, engraving, moulds and dies, small hole drilling, machining of carbides and aerospace applications. This electrode was selected for its speed, wear and surface finish. The essential properties of ELLORE +50 graphite are shown in table 1. Electrodes were fabricated into a cubical shape of 25 mm X 25 mm X 50mm with a cylindrical hole drilled centrally for flushing.

Table 1: Properties of ELLOR +50 Graphite

Average Particle Size (µm)	Density (g/cc)	Flexural Strength (Mpa)	Hardness (Rockwell”H”)	Electric Resistivity (µ.ohm. cm)
5	1.86	76	95	850

The workpiece used in the experiments is Inconel 718(UNS NO 7718). Inconel 718 belong to a family of austenitic Nickel-Chromium based high performance alloy having face centered cubic austentic crystal structure. Inconel 718 is oxidation resistant, corrosion resistant and high strength material well suited for application in extreme environmental conditions from -423° to 1300° F. Inconel 718 also have good creep, fatigue, rapture and tensile strength result in their application for fabrication of liquid fueled rockets, rings, casing, Nuclear reactors and pumps, high temperature fasteners, chemical processing and pressure vessels, heat exchanger tubing, cryogenic storage vessels. Alloying elements of Inconel 718 are listed in the table2. The essential properties of Inconel 718 are listed in table 3.

Table 2: The Chemical Composition of Inconel 718

Alloying Element	**Ni**	**Cr**	**Fe**	**Mo**	**Nb(+Ta)**	**Co**	**Mn**
% by mass	**50 – 55**	**17 - 21**	**Balance**	**2.8 -3.3**	**4.75 - 5.5**	**1**	**0.35**
Alloying Element	**Al**	**Ti**	**Si**	**C**	**S**	**P**	**B**
% by mass	**0.2-0.8**	**0.65-1.15**	**0.35**	**0.08**	**0.015**	**0.015**	**0.006**

Table 3: Properties of Inconel 718

Density (g/cm^3)	**Melting Point($^{\circ}C$)**	**Co-Efficient Expansion (µm/m °C)**	**Modulus of Rigidity (kN/mm^2)**	**Modulus of Elasticity (kN/mm^2)**	**Tensile Stength (N/mm^2)**
8.19	**1336**	**13**	**77.2**	**204.9**	**1250-1450**

While doing machining by EDM each cycle has an on-time and off-time is expressed in units of microseconds. Since all the work is done during on-time, the duration of these pulses and the number of cycles per second (frequency) are important. To observe the effect of pulse on-time on MRR, End Wear and SR value of peak current is varied while keeping the other parameter like pulse-off time, servo voltage and electrode feed rate fixed. Metal removal is directly proportional to the amount of energy applied during the on-time[11]. The pulse off-time allows the dielectric fluid to produce the cooling effect and to clear the melted small particles from the gap between tool electrode and workpiece. The surface roughness first decreases with increases in off-time and then increases with increase in pulse off-time[12]. Peak current is the amount of power used in discharge machining, measured in units of amperage and is the most important machining parameter, higher currents will improve MMR but at the cost of surface finish[13].

The machine used for experimentation is numerical control die sinking EDM of Electronica F series from India. Machine is equipped with mean voltage (MV) servo for finish machining. This work used Graphite as electrode material which is employed to get best possible surface finish and for the workpiece used is Inconel 718 which is employed for manufacturing of liquid fueled rockets, rings, casings and various formed sheet metal parts for aircraft and land-based gas turbine engines, and cryogenic tanks. Dielectric fluid used is Kerosene oil having viscosity of 5-6 Cst at $20^{\circ}C$. Dielectric fluid is flushed through the spark gap and is supplied through a hole in the tool. The dielectric fluid serves as a spark conductor, concentrating the energy to a very narrow region. In addition it serves as a coolant to quench the spark and cool the electrodes and as a flushing medium for disposal of the product of machining. The electrode is drilled and the dielectric is directly fed through it. The pressure applied is 2 kg/cm^2. Components machined using pressure flushing are always slightly tapered. This is due to the particles being forced up the sides of electrode producing lateral discharges. Sometimes this slight taper is desirable as in the case of press tools. The effect of various EDM process parameters like current, on-time, duty factor and polarity on MMR, end wear % and surface finish, were determined through experimentation. After the set up, various machining parameters are selected as given in the table 4. The dielectric fluid is pumped through the central hole in the electrode and then the spark is switched on. After the experimentation the surface roughness was measured using MITUTOYO SJ-210P portable instrument. The surface rougness(Ra) is the arithmetical average of the roughness.

Table 4: Experimental Condition

Experimental Conditions	**Descriptions**
Workpiece	Inconel 718
Electrode	Copper infiltrated Graphite ELLOR +50
Polarity	Negative
Current(A)	2.5, 5.5, 8
Ton	2, 12, 51
Duty Factor %	33, 50, 67
Dielectric fluid	Kerosene oil

III. RESULT AND DISCUSSIONS

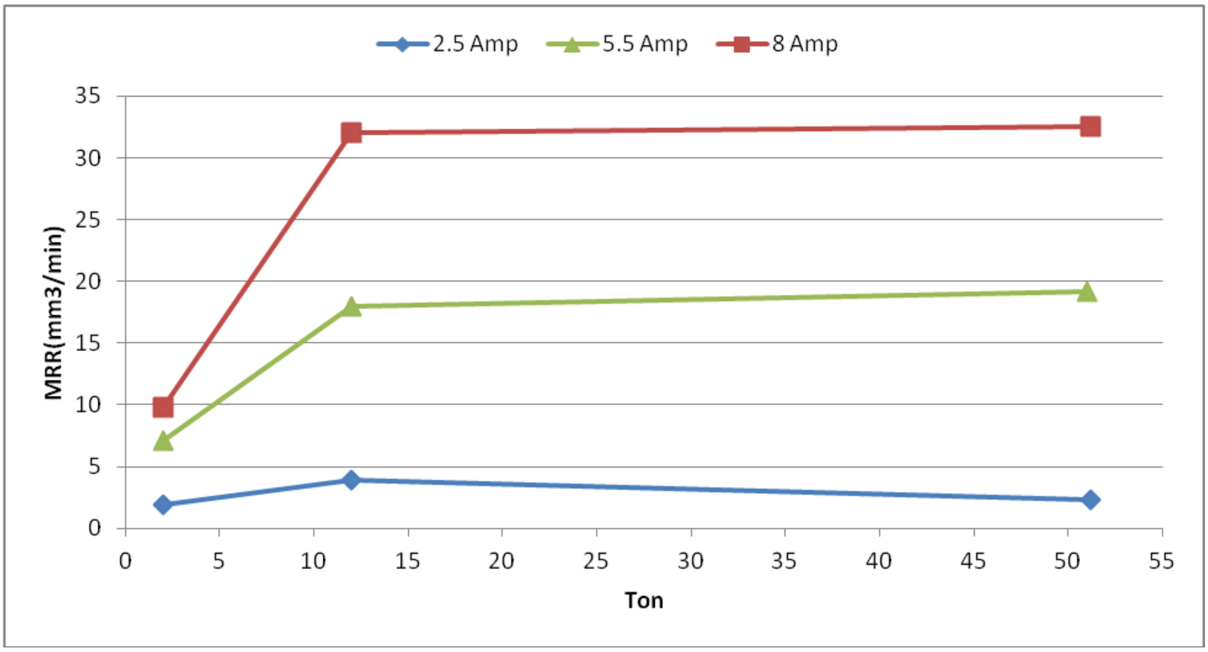

Fig 2: MRR at various values of discharge current and Ton

The result of figure.2 shows the relationship between current and MRR, with increase in discharge current the material removal rate increases. For experimental value of 2.5 Amp and on-time of 2 µs , we get minimum MRR of 1.95 mm^3/min and for value of 8 Amp and on-time of 51 µs, we get maximum of 32.58 mm^3/min. The MRR increase sharply with increase in discharge current from 2.5 Amp to 8 Amp and it increase sharply when on-time increase from 2 to 12 µs and there is slight change their after.

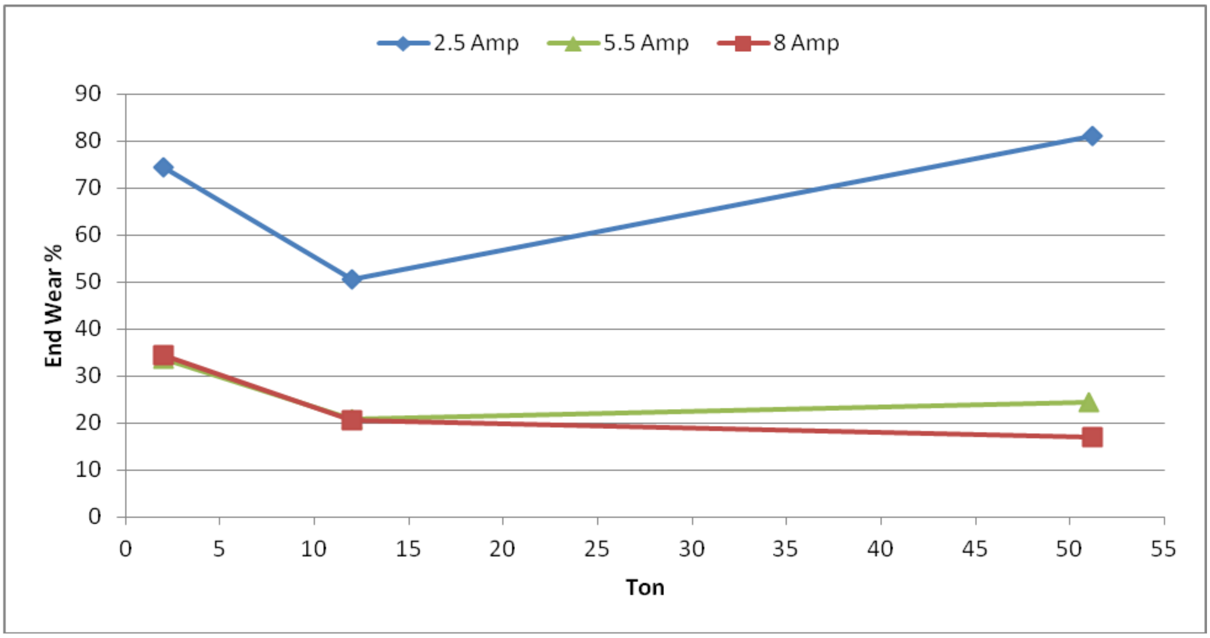

Fig3. End Wear % at various values of discharge current and Ton

Figure. 3 shows the relationship between current and end wear %; with increase in discharge current and on-time the end wear % decreases. For discharge current of 2.5Amp and on-time of 2 µs we get end wear of 74.38 % , which reduced sharply for on-time of 12 µs and further increase upto 81.88 % at 51 µs . The end wear % for discharge current of 5.5 Amp and 8 Amp is similar at the beginning (for on-time 2 and 12 µs) and shows insignificantly different values at the end.

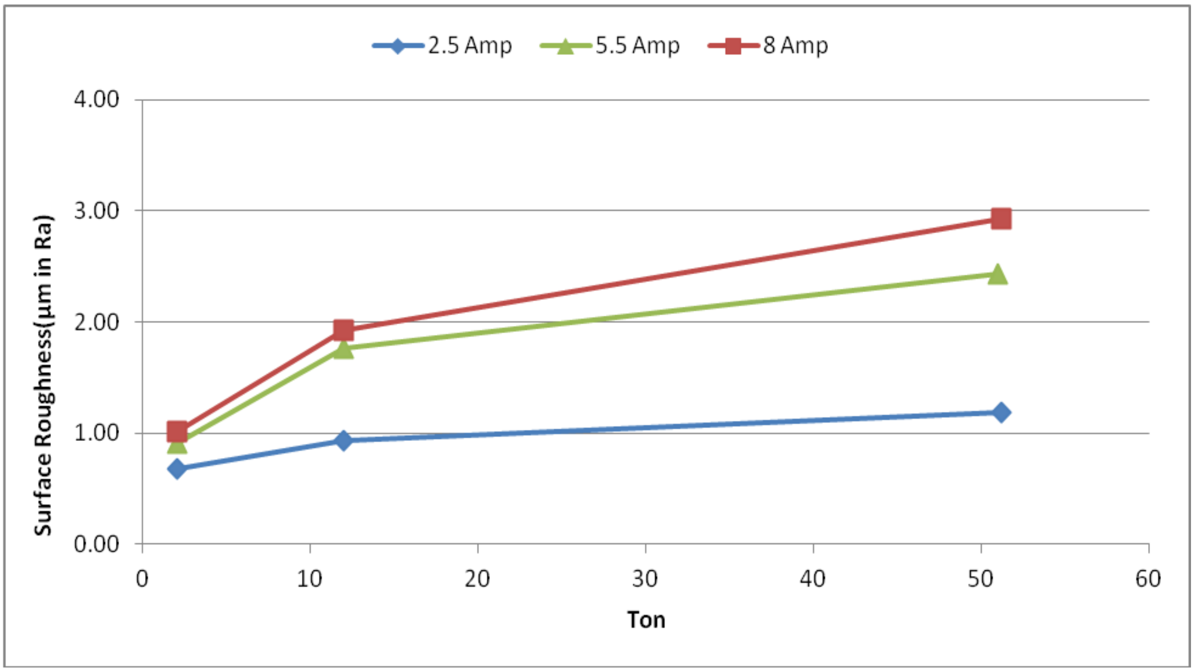

Fig 4: SR at various values of discharge current and Ton

Figure. 4 shows the relation between current and surface roughness of the workpiece, with increase in discharge current and on-time the surface roughness increases. The discharge current leading to the least surface roughness (Ra) was 2.5 Amp, and the Ra value was 0.68 µm. The results of the experiment showed that a variation of the discharge current led to insignificant differences in the surface roughness, with the highest values of the current leading to Ra value of 2.93 µm.

IV. CONCLUSION

From this research, it can be inferred that the electrode tool with negative polarity performs better in terms of elevated MRR and lesser tool wear. It was seen that discharge current and Ton values had direct impact on the MRR and surface finish, higher the discharge current more is the MRR and SR and vice-versa. Highest MRR is achieved when discharge current is highest along with when Ton is highest. Also, discharge current and Ton values inversely affects the surface smoothness i.e. when discharge current and Ton is highest, the surface roughness is found to be maximum. A minimum surface roughness of 0.68 µm is achieved on least amperage of 2.5Amp and Ton of 2 µs, whereas, maximum MRR of 32.58mm^3/min and minimum End Wear% of 16.91 % was achieved on 8.5Amp discharge current and Ton of 51.2 µs.

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