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Review on Machining of Inconel Based Super Alloys by Electro Discharge Machining Process

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Abstract

Electric discharge machining (EDM) process generally used for burrs free, less metallurgical damage, stress free and very precise machining and produces mould cavity, deep holes, complex shapes & size by arc erosion in all types of electro-conductive materials. In this process, the metal is removed from the work piece due to erosion caused by rapidly recurring spark discharge taking place between the tool electrode and work-piece. Tool electrode and wok-piece both submersed into the dielectric fluid. The main aims of this review paper work is to present the consolidated information about the contribution of various researchers on the machining applications of electric discharge machining process on Nickel-Base Super alloys materials, utilization of various tool and techniques for correlating experiment results and applications of product through the EDM. Nickel-Base Super alloys materials is widely used for fuel tanks, aircraft & rocket engine components, nuclear fuel element spacers, casings, fasteners, rings, seal, measuring instrument, cryogenic storage tanks and automobile components etc.

Keywords: Electric discharge machining, Inconel super alloy, Material removal rate, Surface roughness, Tool wear rate

I. INTRODUCTION

EDM as a process was introduced over fifty years ago; improvements in technology have led to increases in cutting speeds and accuracy of machining components. Electric Discharge Machining process originates around 1770, when English Scientist Joseph Priestly discovered the erosive effect of the electric discharges (sparks) 1950s, which provided the first consistent dependable control of pulse time and a simple servo system control circuit to automatically sense the required inter-electrode gap between the tool and the work-piece [1]-[2]. In 1980s, the beginning of Computer Numerical Control (CNC) in EDM brought tremendous development in improvising the efficiency of the machining process. Recent EDM machines are so stable these days that these can be operated round the clock under adaptive control system monitoring. Developing from initially tool making industry sectors of press tool and mould tools, the EDM process is now mainly found within automobile, aircraft, aerospace, nuclear , food processing, motor sport, medical and scientific industries.

At present, the modern industries starting using the EDM for machining of various materials such as cobalt based super alloy, nickel based super alloy, high-speed tool steel, titanium based alloy, aluminum particle reinforced material and metal matrix composites etc. In this paper literature, review on the machining of nickel based super alloy material by Die sinking EDM. Nickel based super alloys may contain alloying additions of chromium, cobalt, aluminum, titanium, rhenium, ruthenium and other elements. The use of super alloys can allow the operating temperature to be increased from 1200F to 1300F. Nickel based super alloys widely used for aerospace engine components, power-generation turbines, rocket engines, chemical processing plants, petrochemical, food processing, nuclear reactor, pollution control equipment and other tough environments applications. Super alloy is also known as high performance alloy and has several characteristics of the nickel-based super alloys are creep resistance at elevated temperatures, thermal shock resistance, good surface strength and good corrosion resistance etc [45].

II. DIE SINKING EDM

A- Introduction of EDM

This process is generally used for producing blind cavities, mould, desire complicated shapes and sizes; here the electrode and a work piece are submerged in an insulating liquid, known as dielectric fluid. Thus, principally this is alike to that of general EDM process. The main desirability of EDM over traditional machining processes such as unwanted metal removal using different tools and grinding is that this technique utilizes thermo-electric process to erode undesired materials from the work piece by a series of discrete electrical sparks between the work piece and the tool electrode. Both tool electrode and work-piece submersed in to the dielectric fluid. A picture of EDM machine in operation is shown in Fig. 1.

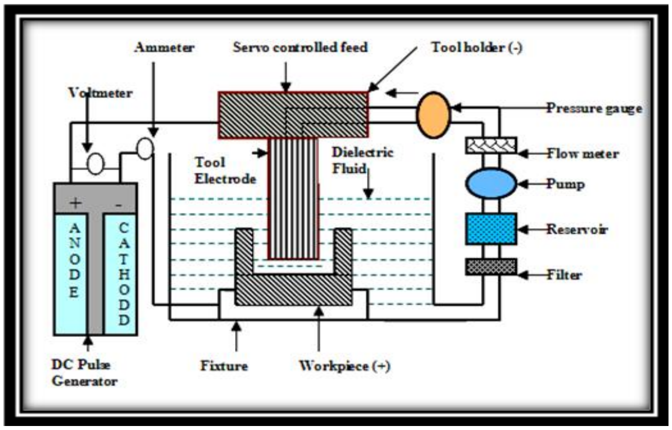

Figure1: Schematic diagram of Die sinking EDM [4]

B- Components of EDM

1) Work-piece- must be all types of the conductive/ semi-conductive material can be machining by EDM.

2) Tool Electrode-The EDM electrode is the tool that determines the shape of the desire hole, cavity and contour to be produced. Tool electrode must be made of all types of electrically conductive material.

3) Servo system- This system used for maintain the predetermine gap between the tool electrode and work-piece.

4) Power supply-The power supply is an important part of any EDM system. It transform the alternating current from the main utility supply into the pulse direct current (DC) required to produce the spark discharge at the machining gap. EDM Power supplies must be able to control pulse voltage, current, pulse duration, duty cycle, pulse frequency and Electrode polarity.

5) The DC pulse generator is responsible for supplying pulses at a certain voltage and current for specific amount of time.

C-Principle of EDM

1) In this process, the surplus material is detached from the work-piece due to wearing away caused by quickly returning electric spark discharge taking place between the tool electrode and work-piece.

2) A predetermine spark gap is maintained between the tool electrode and work piece by a servomechanism as shown in the figure.2. Both tool electrode and work-piece are immersing in a dielectric fluid. The tool electrode connected to the negative terminal and work-piece is connected to the positive terminal.

3) When the voltage applies between the conductive tool electrode and conductive work-piece of material and then sufficient spark developed between the both electrodes.

4) Positive ions and electrons are creating a discharge channel that becomes electric conductive. It is immediately at this point when the spark fly causing impact between ions and electrons produce a channel of plasma, a quick drop of the electric resistance of the prior channel permit that current density attain a very high charge producing an increase of ionization and the formation of a dominant magnetic field.

5) The on the spot spark occurs; enough pressure build up between tool electrode and work-piece as a result of which a extremely high temperature is attain and at such high pressure and temperature a slight metal is melt and eroded. Such localized extreme increase in temperature lead to material reduction material reduction occurs due to immediate vaporization of the conductive and hard material as well as owing to melting.

6) The melt metal is not removed entirely but only partly. One time the potential variation is quiet, the plasma channel rejection longer maintain. Because the plasma channel collapses, it produces a pressure, which leave the molten material therefore forming and at such high temperature and pressure, a quantity of metal is melted and eroded. Such localized excessive

increase in temperature lead to material removal from the work-piece. Material removals occur owing to immediate vaporization of the material as well as owing to melting.

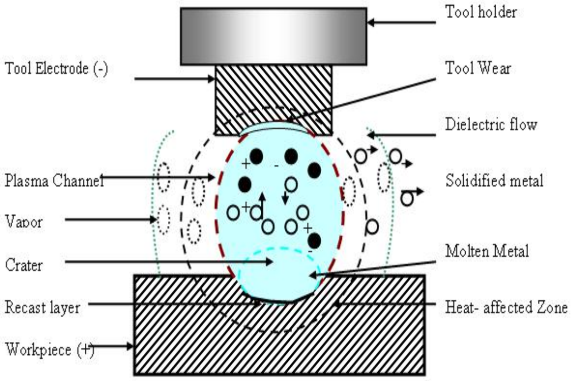

Figure 2: Schematic diagram of Principle of EDM [5]

D-Characteristics of EDM

1) Material removal rate of the work-piece depends on thermal properties of the work materials relatively then its hardness & strength.

2) Tool wear depends on the thermal properties of tool material.

3) Tool electrode must be should have high electrical conductivity, thermal conductivity, high melting point & higher density of tool material.

4) The process of EDM used for any types of conductive /semi-conductive material.

5) Tool electrode & work-piece are not in physical contact during the machining of EDM process.

6) The range of heat-affected zone (HAZ) is limited to 2-4 micrometer of the spark crater.

E-Parameters of EDM

EDM Process parameters mainly classified into two categories:

1-*Process Parameters of EDM*

The process parameters in EDM are used to have an effect on the performance measures of the machining process. Process parameters are usually controllable machining input factors that determine the conditions in which machining performance is carried out. These machining conditions will affect the process performance result, which are gauged using various. The EDM Process involves a large number of input process parameters such as discharge current, peak current, open circuit voltage, gap voltage, pulse-on time, pulse-off time, duty cycle, electrode polarity, pulse frequency, inter-electrode gap, electrode material, electrode shape and size, dielectric flushing pressure, flow of dielectric fluid (normal flow, reverse flow, jet flushing, rotary flushing, vertical flushing, orbiting flushing), tool electrode movement (vibration rotary, vibro-rotary, rotary & stationary), types of dielectric fluid etc [4] .

2. Performance Parameters of EDM

These parameters measure the different process performances of Electric discharge machining outcome. These input process parameters can affect the various response of performance parameters like material removal rate (MRR), Tool wear rate (TWR), surface roughness (SR), radial over-cut (ROC), Over-cut (OC), recast layer thickness (RLT), Heat affected zone (HAZ), Cutting rate (CR), Crater size, corner deviation, dimensional accuracy, micro-crack density, machining time etc [44].

III. LITERATURE REVIEWS

The review of literature is very important milestone in the journey of research work. It reveals what has been done in the particular area and what further need to be done in the chosen field. It, was therefore, decided to review the existing available literature to avoid duplication and to carry forward the research direction. Extensive literature review has been done using different sources, which include books, national and international journal and internet. In order to investigate the outcome of input process parameters on the quality of machining in Inconel 600 super alloy by EDM Process, it is essential to fully understand all the aspect of EDM process and analysis tools, which have already been attempted by different researcher in this field. Literature reviews mention in the table No. I for the optimizations of EDM process and performance parameters for Inconel super alloy Material.

Table-I Optimizations of EDM process and performance parameters for Inconel super alloy material

Authors/ Year	Workpiece	Tool Electrode	Process Parameters	Performance Parameters	Methods or Techniques
Klocke, F., et al.(2004) [7]	Inconel 718 Super alloy	Tungsten electrodes	V, T, η, Polarity & Conc. of Al & Si	MRR, RLT	-

P. Kuppan et al. (2008)[8]	Inconel 718	Electrolytic Copper tube	I_p, T_{on}, & η	MRR & DASR	• RSM Method
Che-Chung Wang et al.(2009) [9]	Ni-based super alloy	-	Polarity	RLT	• Taguchi method
P.S. Bharti et al. (2010) [10]	Inconel 718	Copper	SF, T_{on}, I_d, η, V_g, F_p electrode lift time	MRR, TWR & SR	• Taguchi and ANOVA
S. Rajesh et. al .(2010) [11]	Inconel 718	Copper with tubular cross-section	Ip, η, Fp Sensitivity control & Gap control	SR, RLT & Micro-Structure	• RSM method CCD
Ghewade et al. (2011) [12]	Inconel 718	Copper	I_p, V_g, T_{on} η	MRR, EWR, ROC & TA	• Taguchi method
S. Prabhu et al.(2011) [13]	Inconel 825	Copper	T_{on}, T_{off} Ip & V_p	SR	• Taguchi method
D Sudhakara et al. (2012) [14]	Inconel 718	Copper	I_p, T_{on}, η	MRR, SR & Hardness	• Taguchi methods
Naveen Beri et al.(2012) [15]	Inconel 718	Copper Tungsten	I & ,Electrode polarity	MRR,TWR,& SR	• X-RAY diffraction Analysis (XRD)
Bharti S. P .et al.(2012) [16]	Inconel 718	Copper	I_d, T_{on} Vg, SF, F_p, η & Tool Electrode Lift	MRR, SR	• ANN & GA
S. Rajesha et al. (2012) [17]	Inconel 718	Copper	Ip, η, Vg, F_p , and sensitivity control,	MRR,TWR & SR	• RSM method
Priyaranjan Sharma et al.(2012) [18]	Inconel-600	Rotary brass hollow tubular	Ip, V_g, T_{on}, T_{off} & F_p	MRR, EWR, OC , TA	• Taguchi method
Harshit K Deve et. al.(2012) [19]	Inconel 718	Copper	I, Vg, T_{on}, η	MRR	• Taguchi & ANOVA

S. Dhanabalan et al. (2013) [20]	Inconel 718	Copper	I_p T_{off} & T_{on}	MRR,EWR, WR	• Taguchi method
Mao-yong LIN et al. (2013) [21]	Inconel 718	Tungsten carbide	I_p, T_{on}, T_{off} & S_g	MRR & EWR	• Grey-Taguchi method
S. Ahmad et al (2013) [22]	Inonel718	Copper	I_p & T_{on}	MRR, EWR & SR	• Taguchi methods
Sengottuve. P et al. (2013) [23]	Inconel 718 Super alloy	Copper	T_{on}, T_{off}, I_p , F_p, & tool geometry	MRR,TWR & SR	• ANOVA • Non linear fuzzy logic
Uday A. Dabade et al.(2013) [24]	Inconel-718	Aluminum & Brass	I, F & Ton,	TWR, MRR	• Taguchi method
M Manohar et al.(2014) [25]	Inconel 718	Copper	I_p, T_{off} ,T_{on}, V, F_p	MRR, EWR, SR, RLT	• SEM
C.P Mohanty et al. (2014) [26]	Inconel 718 .	Brass, copper & graphite	OCV, I_d, T_{on}, F_p, η & tool material	MRR, SR & ROC	• RSM Methods • MOPSO
P. Karthikeyan et. al. (2014) [27]	Inconel 718	Copper	T_{on}, T_{off}, I_p, Fp, Tool geometry	MRR & TWR	• Taguchi methods
Kuriachen B. et al.(2014) [28]	Inconel 718	Copper	Vg, F_w , F Capacitance	MRR, TWR & OC	• RSM & ANN methods
Buta Singh et. al. (2014) [29]	Inconel600 alloys	Copper, Brass and Copper-tungsten	Ip, Ton, Vg, Electrode material (Cu, brass, Cu-W)	MRR & EWR	• Taguchi method • ANOVA analysis
V. Muthukumar et. al.(2014)	Incoloy 800	Copper	I, V, T_{on} & T_{off}	ROC	• RSM method • CCD

[30]					
K. J. Sabareesaan et. al.(2014) [31]	Inconel X750	Brass Electrode	I_p, T_{on} & V	MRR,EWR & SR	• Box Behnken design of experiments
A. Torres et al (2015) [32]	Inconel 600 Alloy	Copper	I, T_{on}, η, polarity,	MRR, EW & SR	• RSM method
T.R. Paul et. al.(2015) [33]	Inconel 800	Copper	T_{on}, T_{off}, & I	MRR	• RSM Method
Harpinder et al. (2015) [34]	Inconel 718	Graphite	Ip, Ton, η	MRR, EWR, SR	• EDM process
Harmanpreet et. al.(2015) [35]	Incoloy-800	Copper	I, T_{on}, and V_g	Machining time & MRR	• ANN & GA method
P Shankar et. al.(2015) [36]	Inconel-718.	Brass Electrode	T_{on}, T_{off} & I	MRR & TWR	• Central composite rotatable design
A. Torres et. al.(2015) [37]	Inconel 600	Copper	I, T_{on}, η, t_i	MRR, EW & SR	• Factorial design • ANOVA
KJ Sabareesaan et. al.(2015) [38]	Inconel X750	Brass	I_p, T_{on}, V_g	MRR	• RSM method
A. Torres et al.(2015) [39]	Inconel 600	graphite electrodes	I, T_{on}, & η	SR	• DOE-Factorial design
T. Ponnarasan et al.(2015) [40]	Inconel 600	Copper	T_{on}, I_d, & Vg,	MRR & SR	• Taguchi and ANOVA

Table-II Nomenclature

Nomenclatures		Nomenclature	
EDM	Electric Discharge Machining	T_{on}	Pulse-on time
RLT	Recast layer thickness	T_{off}	Pulse-off time
MRR	Material removal Rate	V_g	Gap Voltage
TWR	Tool Wear Rate	I_p	Peak Current
SR	Surface Roughness	I_d	Discharge Current
OC	Over-Cut	η	Duty cycle
ANOVA	Analysis of variance	S_v	Servo voltage
MOPSO	Multi Objective Particle Swarm Optimization	F	Dielectric flow rate
GRA	Grey relational Analysis	OCV	Open circuit voltage
ANN	Artificial Neural network	F_p	Flushing Pressure
GA	Genetic algorithm	T_w	Pulse width
CCD	Central composites design	N_E	Electrode rotation
RSM	Response surface methodology		

IV. CONCLUSIONS

Latest advancements in different aspects of electro-discharge machining that reflect the state of the art in these processes are present in this review paper. Researcher works on enhancement of MRR, cutting speed, reduction of TWR, improve SR by experimental investigation. In this review paper collection of die sinking EDM research publications on machining of Nickel-base Super alloys material by EDM. This paper work very helpful for researcher, because various types of information about the research direction of EDM such as various grade of Nickel-based super alloy, different types of electrode, process and performance parameters and used various types of optimization techniques etc. An essential observes on different research works is also presented and following clarification are made based on this review work.

1) This review work observe the EDM machining process on the material of Inconel super alloy using different types of electrode, parameters and optimization techniques .

2) Very less research work in Inconel super alloy 600 grade compare to another super alloy grade.

3) In this review work, optimization techniques mostly used are Taguchi, RSM, GRA, Fuzzy logic, MOPS, GA, and ANN etc.

4) Very less research work by Swarm Intelligence optimization techmiques such as: Ant Colony optimization (ACO), Particle swarm Optimization (PSO), Swarm based network Management,Coperative behavior and swram of robots.

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