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A study to improve the machining characteristics in Electrode Discharge Machining of Inconel 706 Super Alloys

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Abstract*— From the past decade, the utilization of Inconel (Nickel-based super alloy) has been increasing due to its outstanding mechanical properties like resistance to corrosion, high temperature strength etc. Inconel is widely used in hot section of gas turbines in aerospace industries like turbine blades, disk, combustors etc. Machining of Inconel using conventional method is very difficult due to quick work hardening which tends to deform either the work-piece or the cutting tool. Electrical discharge machining (EDM) is a non-traditional machining method used for machining Inconel in which material removal takes place due to electrical discharge between work-piece and tool. But low MRR and high TWR are the main challenges in this process while machining Inconel. The present article investigates the machining characteristics of EDM in order to improve the material removal rate under different machining conditions and to reduce tool wear rate using tool electrode treated with heat treatment process. From the investigational results, it was observed that improved MRR and reduced TWR were obtained when machined with heat treated tool electrode.

Keywords*— Inconel 706, Electrode Discharge Machining (EDM), MRR, TWR, Heat treated electrodes.

I. INTRODUCTION

The perspective of manufacturing has changed in recent times due to development of advance materials and introduction of various industrial engineering concepts [1,2]. It is a non-traditional method used for machining materials which are conductive in nature and usually possess higher toughness, higher strength to weight ratio, very hard and are tough to machine by other conventional method [3]. EDM has diverse range of applications such as in aerospace, automotive and manufacturing (dies and moulds) industries. Still, lower MRR and higher TWR are the vital difficulties related with this process. Inconel have exceptional combination of properties for example higher toughness and strength, outstanding thermal fatigue properties, better corrosion resistance and better thermal stability. Inconel 706 superalloy was selected as the workpiece material as a substitute of Inconel 718 for manufacturing turbine disk due to its outstanding chemical balance and less prone to the problem of segregation and thus make it perfect for this application. Inconel 706 properties are comparable to Inconel 718 except the lesser percentage of alloying elements and ease of fabrication. Inconel 718 is the major contributor for manufacturing a jet engine (i.e. almost 50% by weight) [4], [5]. Fig. 1. shows the material distribution in GE CF6 aircraft engine. Now a days improvement in engines of gas turbine with excellent temperature capability (used for firing) besides compressor ratio, it became essential to apply Inconel706 material for rotors [6]. The problems like chemical affinity, work hardening phenomenon, lower thermal conductivity and abrasive nature are often observed while machining Inconel [7,8]. To overcome these problems, non-traditional machining method like EDM is successfully employed for machining of Inconel.

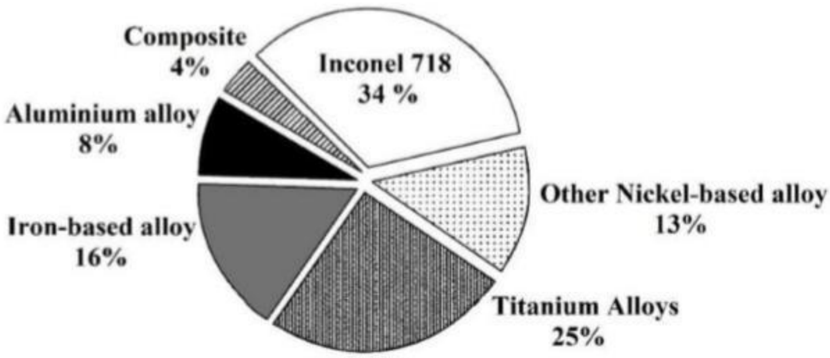

Fig. 1. Distribution of material in GE CF6 aircraft engine [9]

Furthermore, no literature was available to explore the effects of heat-treated copper electrode influencing MRR, SR and TWR of the machined surface. Various characteristics of process capabilities of 706 material super alloy during EDM was tried in this work. The scope of machining was explored by varying peak discharge current in form of process performance (i.e. MRR, TWR and SR) with both with and without heat treated electrode.

II. EXPERIMENTAL DETAILS

A. Material selection and workpiece preparation

Inconel 706 superalloy was chosen as a work material. Work material chemical composition has been presented in Table 1. Table 2. Shows the various properties of work material. Molybdenum is omitted from Inconel 706 material to enhance forging capability and reduced the content of niobium to minimize the possibility of phenomenon of segregation and freckle formation. Chromium was designated to attain better oxidation resistance and lower magnetic permeability. Nickle was carefully chosen to the minimum level for reducing cost [10]. The specimen was stress relieved before machining. All the samples were heated in a tubular furnace (up to 800°C) for one hour followed by cooling at room temperature. If not done, may lead to machine components distortion (failure) due to residual stresses in the parent material. The copper is selected as tool material in two forms i.e. heat treated (HT) and without heat treatment (WHT). Heat treatment was done by using electric furnace at a temperature of 350oC for 2.5 hours followed by water quenching.

TABLE 1. CHEMICAL COMPOSITION OF INCONEL 706 [11].

Alloy (%)		Ni+Co	Cr	Fe	Nb+Ta	Ti	Co	C	Mn	Si	S	Cu	Al	P
Inconel	Min.	39	14.5	Bal.	2.5	1.5								
706	Max.	44	17.5		3.3	2	1	0.06	0.35	0.35	0.02	0.3	0.4	0.02

TABLE 2. PHYSICAL AND MECHANICAL PROPERTIES OF INCONEL 706 [11].

Properties of Inconel 706	Specifications	Properties of Inconel 706	Specifications
Density	8.05 g/cm3	Elongation	19%
Yield strength (0.2% offset)	993 MPa	Modulus of elasticity	210 kN/mm2
Thermal conductivity	12.5 W/mK	Melting range	1334–1371 ◦C
Tensile strength	1282		

B. Machining Details

The investigational work was performed on EDM (Model: ELEKTRAPULS PS 35 from Electronica Machine Tools, Pune, India). Table 3. shows the machining conditions. A cylindrical pure copper (with and without heat treated) with 6mm diameter was used as a tool to erode the workpiece material. The schematic of the experimental set-up is shown in Fig. 2. In this process, the repeated discharges occur to machine the electrode shape on workpiece material. The machining occurs when the electrode moves in vertically downwards direction.

Fig. 2. Schematic diagram of sinking EDM.

In this change of electrode geometry would occur while rough machining, hence change the electrode for executing final finishing operation. The values of current and voltage are monitored by numerical control system and simultaneously controls the axes movements and pulse generator. Therefore, electrical energy is transformed into thermal energy. Generally, electrical discharge produced has a temperature range of around 8,000°C to 12,000°C which is sufficient to melt and vaporize workpiece (conductive).

TABLE 3. MACHINING PARAMETERS

Parameter (Units)	Value (s)	Parameter (Units)	Value (s)
Dielectric	Kerosene	**Flushing pressure (lb/in^2)**	5
Gap voltage (V)	60	**Polarity**	Positive
Pulse on time (μs)	100	**Duty cycle**	9 (machine setting)
Peak current (A)	4,8	**Machining time (min.)**	3

III. RESULTS AND DISCUSSION

A. Surface roughness (SR) analysis

Mitutoyo SJ-400 surface roughness tester was used for measuring SR of work surface. As the peak discharge current increases, therefore intensity of spark per pulse increases resulting to a larger crater depth formation on the work surface formed, henceforth SR increases. The same is the case with HT electrode. Fig. 4(a). displays the result of peak current and on SR of the workpiece material for both HT and WHT electrodes. Figure 3(a), (b), (c) and (d) investigated the differences in size of crater for the varied peak current. The minimum surface roughness achieved is 3.19 μm at a peak current of 4A from WHT electrode. The material removal is calculated as ratio of change in material change during machining to the time taken [12,13].

3.2 Surface topography analysis

The machined surface was exposed to a FE-SEM (Make: FEI, Model: Quanta 200 FEG). At 4A peak discharge current machined WHT electrode, only small amount of material is melted due to lesser spark intensity which can be easily flushed by flow of dielectric and leads to formation of smaller size craters on the work surface which results in lesser surface roughness as shown in figure 4(a). Similarly, as the discharge current increases leads to increase in crater size. This, in turn, increases surface roughness as displayed in figure 4(c). The FESEM analysis revealed that at 8A discharge current with HT electrode high density of micro holes, micro globules, melted debris and larger crater sizes resulting to rough machined surface as shown in figure 4(d).

During flushing, a part of the molten work material is flushed; nevertheless, few air bubbles get entrapped. During solidification these air bubbles get collapsed and helps in generating micro hole on the machined area as shown in fig. 4 (c) and (d). In contrast, the tendency of formation of larger crater size and micro globule are significantly reduced when machined at 4A peak current with HT electrode due to fine discharge occurred except few micro holes and melted debris as shown in figure 4(c).

B. Material removal rate (MRR) analysis

It is investigated that as the peak discharge current increases, MRR increases as shown in figure 4(b). As peak current increases lead to rise in energy per pulse which further helps in rising temperature, this, in turn, quick melting of work surface at sparking zone. The highest MRR attained at 8A peak current with value 42 mm3/min form HT electrode. MRR also increases in case of HT electrode because of there might be more electrons drift speed due as peak current increases with more kinetic energy.

C. Tool wear rate (TWR) analysis

As peak current starts increasing, TWR increases as shown in figure 4(c). As peak current increases, TWR increases for constant machining parameters because higher peak current leads to increase in spark energy causes more erosion of material from tool electrode, which result in increases TWR. The TWR is lesser in case of HT electrode as compared to WHT electrode because of there is high hot hardness temperature in HT electrode. The lowest TWR is 0.015mm3/min at 4A (peak current) from with HT electrode.

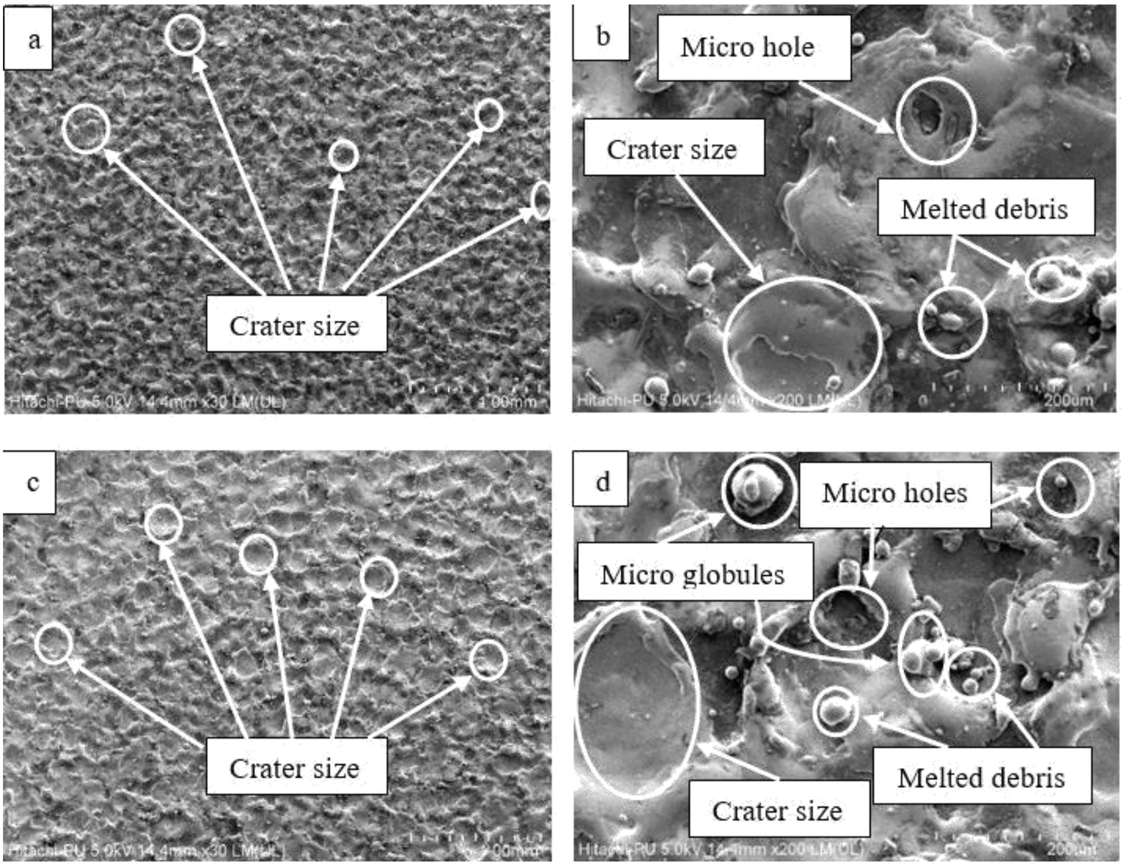

Fig. 3. FESEM images of Surface topography analysis of machined surface, (a) at 4A (WHT electrode); (b) at 4A (HT electrode); (c) at 8A (WHT electrode); (d) at 8A (HT electrode).

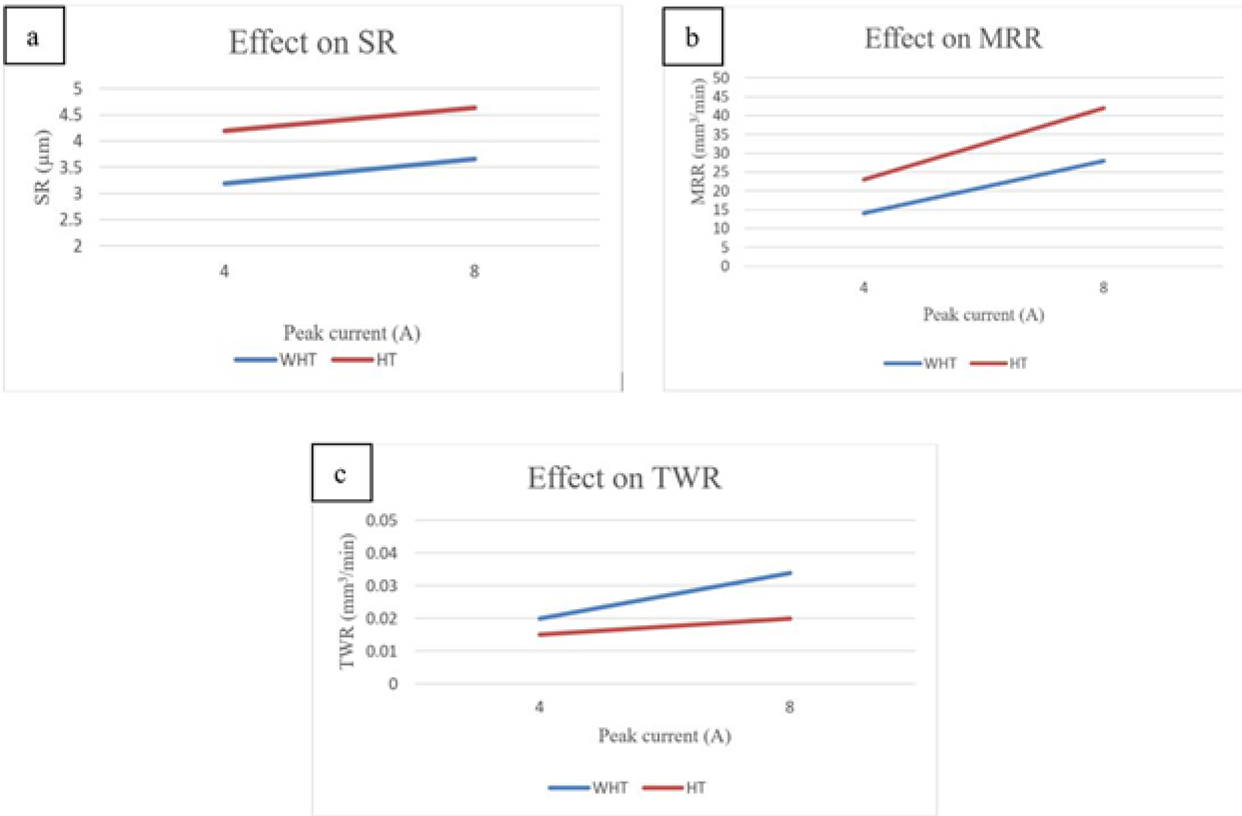

Fig. 4. Shows the peak current effect with both HT and WHT electrodes on (a) SR, (b) MRR and (c) TWR.

IV. CONCLUSIONS

For the aim of achieving the possibility in engineering of gas turbine parts using this process, effect of heat-treated electrode along with increase in peak current on EDM performance characteristics of the parent material is evaluated. Grounded on this investigation, the following conclusions are given below:

- It was observed that heat treated electrodes offers better MRR, lesser TWR but poorer surface finish.
- It was revealed that peak discharge current significantly effects MRR, TWR and SR.
- Microstructure analysis revealed that no micro cracks were found on the machined area due to the higher toughness of the work material (i.e. Inconel 706).
- Also, microstructure analysis exposed that micro holes, melted debris and micro globules are more prominent at higher peak current with heat treated electrode and therefore offers increased surface roughness on machined area.

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