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Effect of Higher Peak Current and Pulse Duration on EWR of Copper Electrode When Electrical Discharge Machining (EDM) of Inconel 718

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Abstract. In this work, the electrode wear rate (EWR) and electrode surface characteristic of copper electrode when EDM of Nickel Based Super Alloy, Inconel 718 at higher peak current and pulse duration were analyzed. Experiments were conducted using Inconel 718 as a work piece and copper as an electrode with a kerosene dielectric under different peak currents and pulse durations. Peak current, I_p within a range of 20A to 40A and pulse duration (or pulse on-time), t_{on} within a range of 200μs to 400μs are selected as the main parameters. In this study, EWR were measured using digital weight balance (accuracy 0.01mg) and by using Scanning Electron Microscope (SEM), the surface texture of the electrode in order to evaluate the material deposited on the electrode surface. The results have shown that machining at a lowest peak current of 20A and highest pulse duration of 400μs yields the lowest electrode wear rate (EWR) of -0.01mm^3/min. The pulse duration is significantly affecting the EWR. It also revealed that, the deposited of carbon and work piece material is occurred on the electrode surface for all machining conditions.

Introduction

One of typical problems with EDM machining operations is high cost of tooling due to electrode wear rate (EWR) and that is the major issue for prolonged machining especially when machining of difficult to cut material such Nickel based super alloy [1]. Nickel based super alloy, Inconel 718 is an aerospace material and considered one of the most difficult-to-machine material which attributed to its ability to maintain hardness at elevated temperature, very poor thermal properties, high toughness, high hardness, and high work hardening rate and consequently it's very useful for hot working environment. Formation of complex shapes by this material along with reasonable speed and surface finish is not possible in traditional machining. Usually, a nonconventional machining method like electrical discharge machining (EDM) is chosen for machining Inconel 718 in order to overcome such limitations [2].

Copper became the metallic electrode material of choice for EDM even though it wear rate is higher due to the melting point temperature of copper is low but copper have high in electrical and thermal conductivity properties. Copper can produce very fine surface finishes, even without special polishing circuits [3]. Result from an experiment done by Kumar et al. [4] when EDM of Inconel 718 shows that an increase in pulse duration up to 750μs has improves the EWR but at higher peak current will affect the EWR adversely. Bharti et al. [2] used copper electrode when EDM machining on Inconel 718. He found that the EWR increases with the increase in discharge current. EWR also increases initially with the increase in pulse-on-time but after certain value it decreases due to the deposition of carbon particles on tool electrode at a high temperature. According to Ghewade and Nipanikar [5], the EWR is mainly influenced by pulse-on time and duty cycle. Whereby, the effect of peak current is less on EWR. Rajesha et al. [6] also claimed that electrode wear is highly influenced by pulse on time when EDM machining of Inconel 718 by using copper electrode. Thus, the objective in this research is to study the effect of higher peak current and pulse duration on copper electrode when EDM machining of Inconel 718.

Experimental Setup

The experiments were carried out on a standard CNC EDM machine, *Sodick AQ55L* with positive electrode polarity. Nickel base super alloys, Inconel 718 were selected as the material for the work piece (specimens 40mm x 30mm x 10mm) and Copper as a tool electrode with diameter of 10mm. The EDM experimental conditions and parameters are summarized in Table 1.

Table 1: Experimental conditions and parameters

Parameters	Levels
Work piece material	Inconel 718
Tool electrode	Copper
Peak Current, I_p (A)	20, 30, 40
Pulse duration, t_{on} (μs)	200, 300, 400
Pulse interval, t_{off} (μs)	Based on 80% duty factor
Voltage, V	120
Electrode polarity	Positive
Dielectric fluid	Kerosene
Depth of cut	3mm

Before experimentation, the work piece top surface was flattened using a surface grinding machine. The initial weight of the work piece and electrode was weighed using a 0.01mg accuracy digital weight balance. The work piece was held on the machine table using a fixture shown in Fig 1. The time taken for machining and the weighed of electrode after machining are measured.

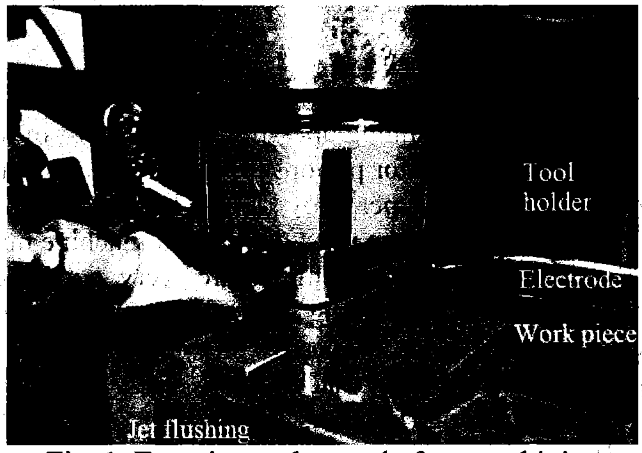

Fig. 1. Experimental setup before machining

The EWR were calculated using the Eq. 1. In this research, a constant duty factor was used for the purpose of maintaining machining efficiency. The formula for duty factor is stated in Eq. 2.

$$\text{EWR (mm}^3\text{/min)} = \frac{\text{Mass loss of electrode (g)}}{\text{Density of electrode (g/mm}^3\text{) x machining time (min)}} \quad (1)$$

$$\text{Duty factor (\%)} = \frac{\text{Pulse duration (}\mu\text{s)}}{\text{Pulse duration (}\mu\text{s) + pulse interval (}\mu\text{s)}} \quad (2)$$

Result and Discussion

Effect of peak current and pulse duration on EWR. The effect of peak current and pulse durations on the EWR is shown in Fig. 2. In this study, the highest EWR obtained at highest peak current (40A) and lowest pulse duration (200μs). This is due to high spark energy at high discharge current causes more material removal from work piece and tool electrode which in turn increases the EWR. However, EWR shows improvement at high pulse duration for each of peak current used respectively. This is due to the longer pulse duration used the pulse interval also increase based on 80% duty factor whereas the flushing have enough time to flush out the debris and to cool down the temperature at machining area and the machining process become more stable thus, reduced EWR. It is suspected that, the deposition of carbon from dielectric and material from work piece on tool electrode at a high peak current for longer pulse duration also contributed for improving EWR. Longer pulse duration tends to increase the possibility of carbon and material deposition on the electrode surface, which function as wear resistant layer for copper electrode and helps to decrease the electrode wear [7]. The lowest EWR is approximately -0.01mm^3/min at 20A of peak current and 400μs of pulse duration. The combination of lower peak current and higher pulse duration used is better for reducing EWR. The negative value for the lowest EWR indicated that, the electrode weight after machining is more than before machining. A dissolved metal from the work piece also revealed deposited on the copper electrode.

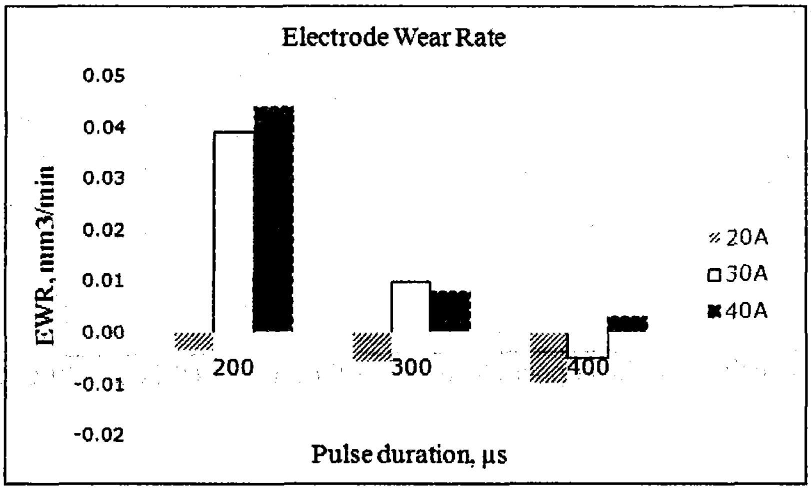

Fig. 2. Effect of peak current and pulse duration on EWR

Effect of peak current and pulse duration on the electrode surface. Examination on the EDM electrode surface for lowest and highest EWR, respectively by using Scanning Electron Microscope (SEM) as shown in Fig. 3 indicated that the electrode surface were deposited with other material and this is proved by EDS analysis as shown in Fig. 4. The deposited material on electrode surfaces were formed by melted material, which was blasted out of the surface by the discharge pressure and subsequently quickly reached solidification temperature through being cooled by the dielectric fluid [8]. It is clear that the morphology of electrode surface was dependent on the applied peak current and pulse duration. At combination of lowest peak current (20A) and highest pulse duration (400μs) as subjected to the lowest EWR, the intensity of deposited material on electrode surface is more than at a combination of 40A and 200μs as subjected to highest EWR, respectively. The result shows that, the highest material content deposited on the electrode surface is nickel from work piece material and carbon from kerosene dielectric. The increment in the electrode weight after machining can be explained with this deposition effect. It is believed that the amount of melted metal, which is subjected to instant vaporization, will be increased as the intensity of the peak current is increased [9] and the heat input to the electrode also increase when higher peak current and longer pulse on is applied and more possibly for melted metal during sparking to deposit on electrode. Further research is needed to understand the effect of deposited material on electrode to the performance of EDM machining and its relation on improving the EWR as well as to the machining accuracy.

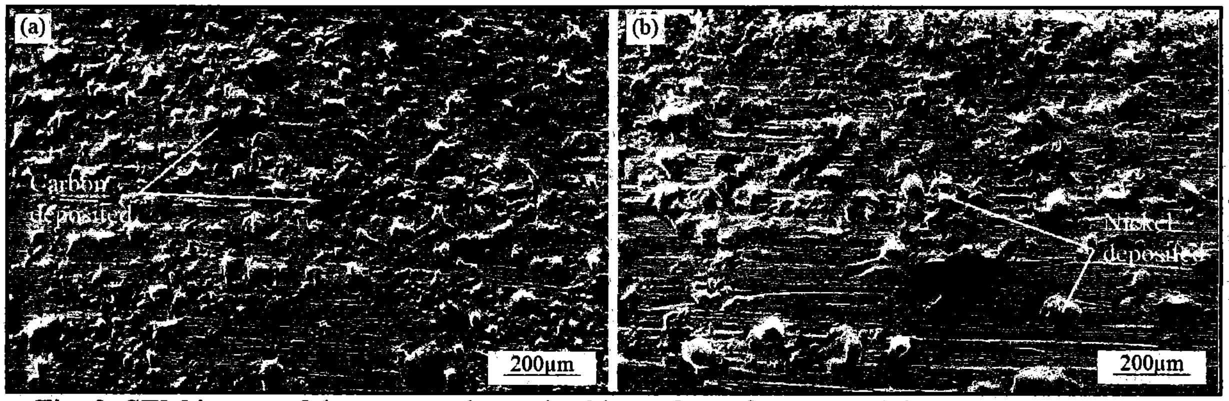

Fig. 3. SEM image of the copper electrode side surface after EDM a) lowest EWR; I_p = 20A, t_{on}=400µs, b) highest EWR; I_p = 40A, t_{on}=200µs

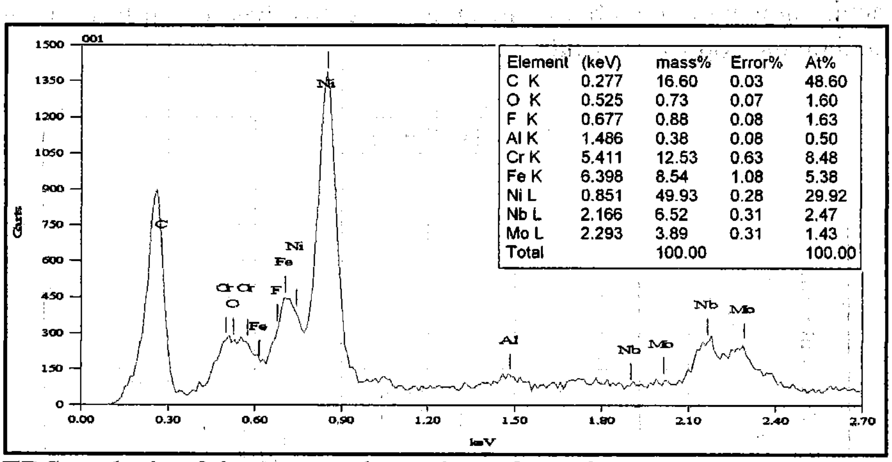

Fig. 4. EDS analysis of the copper electrode surface after EDM (I_p = 20A, t_{on}=400µs)

Conclusion

The effect of higher peak current and pulse duration on copper electrode when EDM of Inconel 718 was examined. The important results are summarized as follows:

1. Pulse duration is significant parameter for EWR. The longer pulse duration used may improved the EWR but affect adversely when higher peak current used.
2. The deposited material on electrode surface may improve EWR and act as wear resistant for electrode.
3. The study shows that, the material deposited on electrode surface occured at all parameters studies. It is believed that, the negative value for EWR is due to the deposition effect on the electrode causes the electrode weight after machining is more than before machining.

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