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# Experimental Investigation of Recast Layer, Heat Affected Zone and Corrosion Resistance in WEDM of Inconel 617

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In this investigation, the effects of input parameters of wire electrical discharge machining (WEDM) process such as pulse current and pulse duration on recast layer thickness (RLT) and heat affected zone depth (HAZ) in machining of Inconel 617 was investigated. Also the corrosion behavior of the machined workpiece was studied. The results showed that RLT increased by increasing pulse current, while HAZ decreased after an increase up to 10 A. Recast layer thickness and HAZ increased by increasing pulse duration. Also, results suggest that WEDM increased the corrosion resistance of workpiece.

**Keywords**: Corrosion resistance, Heat affected zone, Machining, Pulse current, Recast layer

## Introduction

Regarding the difficulty in machining of Inconel alloys with conventional methods, wire electrical discharge machining (WEDM), which was first used in 1960s, can be an alternate process for machining these alloys[1], but the obtained surface integrity by this process should be considered as a challenging problem.[2] Li *et al*.[3], investigated the machining of NdFeB with wire EDM and sinking EDM methods and found, EDM is an effective method to machine NdFeB. Rasheed *et al*.[4], studied the effects of electrode material in machining of micro holes with micro EDM process in the case of shape memory alloys. Kumar *et al*.[5], studied material removal rate of wire EDM process in machining of Inconel X750 and optimized it using Taguchi method.

In this study, the effects of WEDM process inputs on RLT and HAZ depth of Inconel 617 were studied by performing experiments designed by full factorial method. Also the influence of WEDM process on corrosion resistance of workpiece was studied.

## Experimental Details

In this study a five axis CHARMILLES 4020 SI wire EDM machine was used to cut the workpiece. The workpiece was Inconel 617 which is a Ni based material with Cr (22.3%), Mo (8.56%), Al (1.1%), Co (11.7%), Fe (1.24%) and Ti (0.42%). The uncoated brass wire with 0.25 mm diameter was used in machining as tool electrode. The pulse current and pulse duration was selected as input parameters (due to their effectiveness in process outputs according to earlier investigations[6]) and the effects of machining on RLT, HAZ depth and corrosion resistance of work piece were investigated by performing 16 experiments based on full factorial method. The wire feed rate (3 mm/min), wire tension (1.2 N), gap voltage (10 V) and pulse off time (10 µs) were considered as constant conditions during experiments, while the pulse current in four levels (4, 10, 16 and 20 A) and pulse duration in four levels (0.4, 0.8, 1.2 and 1.4 µs) were the input variable parameters.

The recast layer is distinguished from the parent material using SEM images easily, because of its different structure.[7] Therefore the WEGA// TESCAN-LMU scanning electron microscope was used to measure the amount of RLT at 15 different points of the machined surface of work pieces, as the averages of these amounts is recast layer thickness in each case. So the machined work pieces were sectioned, mounted, polished, etched by kalling No. 2 reagent ($CuCl_2$ 5 g +Ethanol 100 cc + Hcl 100 cc), cleaned and dried.

As there was no significant difference between HAZ depth and the parent material in SEM images, a

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combination of SEM images of machined surfaces of workpiece and micro-hardness of these surfaces in line with the thickness in different points, was used to find the heat affected zone depth.[8] So, in this study, the heat affected zone depth was obtained by subtraction of the depth of layer having different micro-hardness with the parent material from recast layer thickness. Potentiodynamic polarization test was performed in a three electrode system containing work electrode, platinum counter electrode and silver reference electrode in a potential range of $E_{Corr}$-350 mV and $E_{Corr}$ +1600 mV with a scan rate of 1 $mV.s^{-1}$ in a 3 wt.% NaCl solution to determine the corrosion behavior. Machined and non machined materials were ground before tests to eliminate the effect of impurities diffusing during pulse on time to the surface of workpieces.

## Results and Discussion

### Recast Layer Thickness

The influences of pulse current and pulse duration on recast layer thickness are demonstrated in Fig. 1. According to Fig 1(a), the RLT is increased by increasing pulse current while the rate of this increase is more in the case of enhancing pulse current from 4 to 10 A as compared to enhancing pulse current from 10 to 20 A. More heat is generated at workpiece surface with increasing pulse current, according to Eq. 1, which creates more melted material leading to more material removal rate as well as higher recast layer thickness.

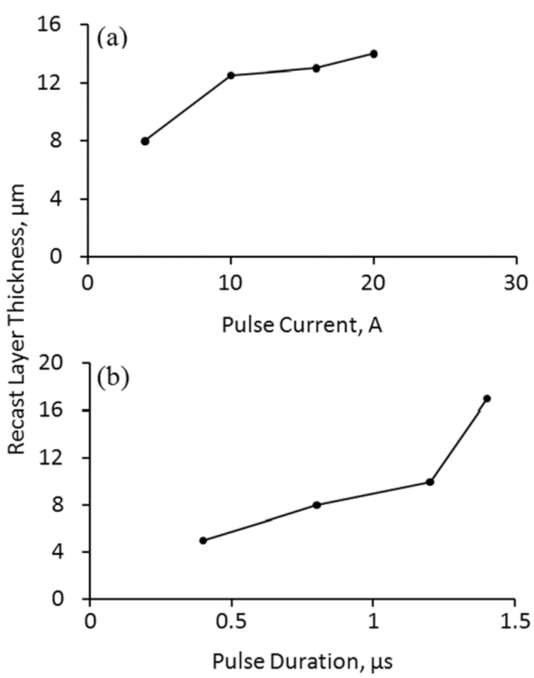


Fig. 1 — Effects of (a) pulse current ($T_{on}$=0.8 µs), (b) pulse duration (I= 4 A), on RLT ($T_{off}$= 10 µs)

In higher pulse currents (more than 10 A), the plasma flushing efficiency (PFE, %) and so the amount of ejected out melted materials is enhanced (which increases the material removal rate and decreases recast layer thickness) besides increasing the amount of melted material. Increasing the amount of melted material at workpiece surface and increasing plasma flushing efficiency counter balance each other's effect leading to lower rate of increasing recast layer thickness at higher pulse currents.

$$Q = R \times I^2 \times T \qquad \dots (1)$$

Where $Q$ is the amount of generated heat during EDM process, $R$ is the resistance, $I$ is the pulse current and $T$ is the pulse duration.

According Fig. 1(b), the recast layer thickness is seen to enhance by increasing pulse duration. It can be explained considering two issues; the first one is related to increasing the amount of generated heat by increasing pulse duration according to Eq. 1, which increases the amount of melted material on workpiece surface and the second one is related to decreasing plasma flushing efficiency by increasing pulse duration which reduces the ability of plasma channel to eject the melted material out. Regarding these two issue, the amount of re-solidified melted material which is attached on workpiece surface creating white layer is increased.

Decreasing plasma flushing efficiency by increasing pulse duration is due to the increasing of plasma channel diameter while the plasma channel temperature remains nearly constant, which leads to decreasing plasma channel pressure and considering the bulk boiling mechanism of material removal in W- EDM, the amount of ejected melted materials from molten craters to out is decreased and the plasma flushing efficiency is decreased consequently.

### Depth of Heat Affected Zone

The effect of pulse current and pulse duration on depth of HAZ is demonstrated in Fig. 2. According to Fig. 2(a), the depth of HAZ is enhanced by increasing pulse current up to 10 A, and then is reduced. Increasing pulse current up to 10 A, generates more heat according to Eq. 1, and so the depth of penetration of heat is increased and so the depth of HAZ is enhanced. Increasing pulse current more than 10 A leads to increasing

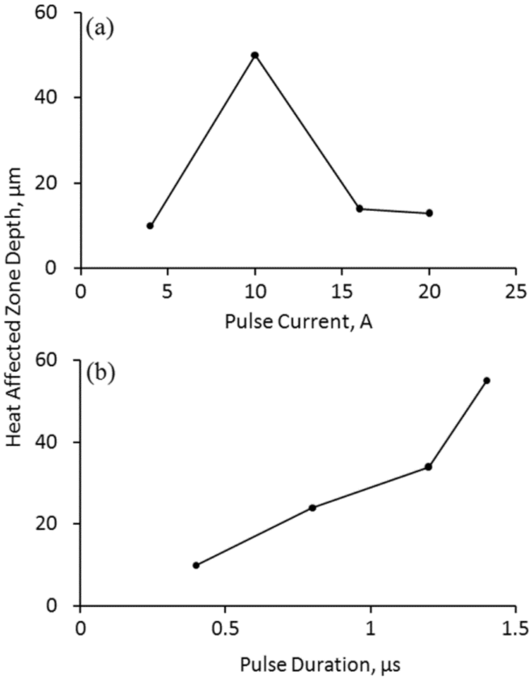


Fig. 2 — Effects of (a) pulse current ($T_{on}$=0.8 µs, $T_{off}$= 10 µs), (b) pulse duration (I= 4 A, $T_{off}$= 10 µs), on HAZ

gap pollution and so the density of plasma channel is decreased and the plasma channel diameter is increased which induces lower depth of HAZ, because the generated heat is distributed in a wider area with lower depth.

According to Fig. 2(b), the depth of HAZ is enhanced from 10 to 55 µm by increasing pulse duration. Increasing pulse duration increases the generated heat which can penetrate to lower layers of workpiece and affect them. Also higher pulse duration increases the heat penetration time, which can enhance the HAZ depth.

#### Workpiece Corrosion Resistance

In Fig. 3, the potentiodynamic polarization test results have been demonstrated for non machined and machined work piece by WEDM process. A broader passive region has been achieved for machined sample with respect to the non machined material. For a metal with weak passivation ability, WEDM process lowers the corrosion resistance due to increase of crystallographic defects. But in the case of Inconel 617, it can be seen that WEDM operation increases the passive region which enhances the corrosion resistance. It is probably due to more crystallographic defects which act as suitable nucleation sites for passive layer.

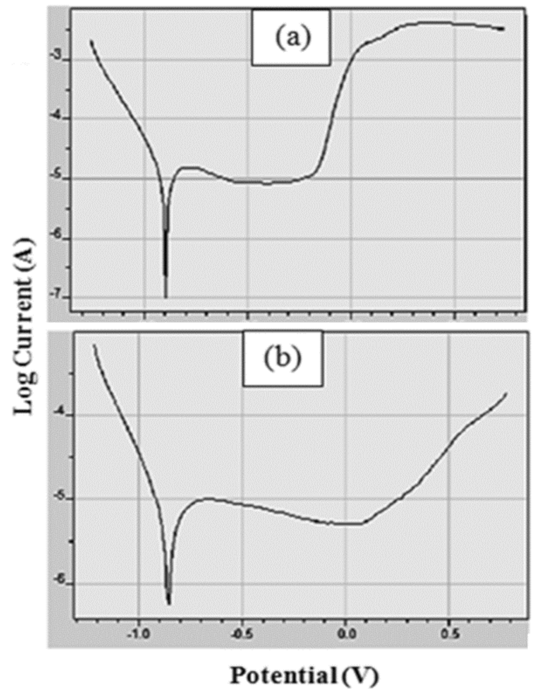


Fig. 3 — Potentiodynamic polarization test results (a) for non machined materials (b) for machined with WEDM process (I= 4A, $T_{on}$ = 0.8 µs, $T_{off}$ = 10 µs)

## Conclusions

The experimental investigation of created RLT and HAZ depth on machined work piece and work piece corrosion resistance in W-EDM of Inconel 617 was done in this investigation. The main conclusions of this study can be summarized as follows:

- Increasing pulse current leads to increased RLT which is generated at machined work piece surface. The HAZ depth increased and decreased in response to increasing pulse current with a peak at 10 A.
- Increasing pulse duration enhances the generated HAZ depth and RLT on machined surface of workpiece.
- The corrosion resistance of machined Inconel 617 by WEDM process is higher than non machined materials due to increased passive region by the machining process.

## Refrences

1 Marimuthu P, Robertsagayadoss M, Edwinpaul N E & Chandrasekaran K, Modeling of EDM progression on heat resistant super alloys using response surface regression, *J Sci Ind Res*, **75** (2016) 475–479.

2 Shabgard M R, Gholipoor A & Hatami M, Wire electrical discharge machining of ASP30 tool steel, *J Mech Sci Technol*, **30** (2016) 3799–3804.

3 Li L, Cheng X, Sima Z & Niu Z, Machinability of NdFeB magnet via wire and sinking EDM methods, *Indian J Eng Mater Sci*, **22** (2015) 407–413.

4 Rasheed M S, Abidi M H & Al-Ahmari A M, Effect of electrode material in micro-electrical discharge machining of micro-holes drilled in shape memory alloys, *Indian J Eng Mater Sci*, **25** (2018) 42–58.

5 Kumar M & Singh H, optimization of process parameters of wire EDM for material removal rate using Taguchi technique, *Indian J Eng Mater Sci*, **23** (2016) 223–230.

6 Shabgard M R, Farzaneh S & Gholipoor A, Investigation of the surface integrity characteristics in wire electrical discharge machining of Inconel 617, *J Braz Soc Mech Sci Eng*, **39** (2017) 857–864.

7 Shabgard M R, Gholipoor A & Mohammadpourfard M, Numerical and experimental study of the effects of ultrasonic vibrations of tool on machining characteristics of EDM process, *The Int J Adv Manuf Technol*, **96** (2018) 2657–2669.

8 Walder G & Richard J, Removal of the heat affect zone created by EDM with pico-second LASER machining, *Procedia CIRP*, **42** (2016) 475–480.