Investigation of Recast Layer Formed on Titanium Alloy Machined by Wire Electric Discharge Machining

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Abstract

Wire-cut electric discharge machining (WEDM) is one of the most emerging non-conventional manufacturing process for machining hard materials and intricate shapes which are difficult or not possible to machine with conventional machining methods. Parameters considered for this study are Pulse ON time, Pulse OFF time and Bed Speed which affects the formation of Recast layer. The formation of the recast layer and its thickness are investigated by using Optical Microscope or Scanning Electron Microscope (SEM).
Keywords: WEDM, Recast Layer, Taguchi Technique, SEM & Minitab

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I. INTRODUCTION

In Wire Cut Electric Discharge Machining, series of sparks are generated between the workpiece and the tool (electrode) so as to machine the workpiece to the required shape. Both the workpiece and the tool is immersed in dielectric fluid. Generally ionized water or kerosene is used as a dielectric fluid. The circulation of the dielectric fluid must be under constant pressure to wash (flush) away the metal particles and assist the machining or erosion process. Workpiece that has to be machined through WEDM process must be electrically conductive.

Since there is no direct contact between workpiece and the tool in WEDM process, material of any hardness can be machined easily.

An impulse source is used to apply impulse voltage between workpiece and the electrode. A controlled servo system is use to maintain the gap, and accomplish impulse discharging in the dielectric medium between workpiece and electrode.

Due to impulse discharging between the workpiece and the tool, small part of the workpiece surface get heated up and the high temperature achieved near the surface and material is melted and removed.

Usually the electrode wire is connected to the negative terminal and the workpiece is connected to the positive terminal of the impulse power source. The resulting high temperature may reach from 8000 to 12000 ^oC and the dielectric liquid flushes away the melted metal. The working principle is shown in the figure 1.

The effectiveness of the whole process depends on number of input process parameters such as Pulse ON time, Pulse OFF time, servo voltage, peak current, dielectric flow rate, wire feed, and wire tension.

The electrical parameters selected for the WEDM process has a great influence on the surface characteristics. The surface integrity is important aspect of the industries and the surface integrity significantly influence the life, performance and the reliability of the components.

The microscopic study of the machined workpiece through WEDM reveals three kinds of layers

- Recast layer
- Heat Affected Zone
- Converted layer

While machining the workpiece through WEDM there will be the formation of hard and brittle layer if the molten metal from the workpiece while machining has not been flushed away correctly by the dielectric fluid. If the flushing is not proper, the molten metal re-solidifies and it gets hardened and adhered to the machined surface because of cooling effect of the dielectric fluid. The layer formed above the surface is about 2.5 to 50 microns and it is known as recast layer.

The recast layers so formed is extremely hard and brittle, and the surface is porous and may contain micro cracks which is not a good characteristic of a machined surface. Such surface should be removed before using these products.

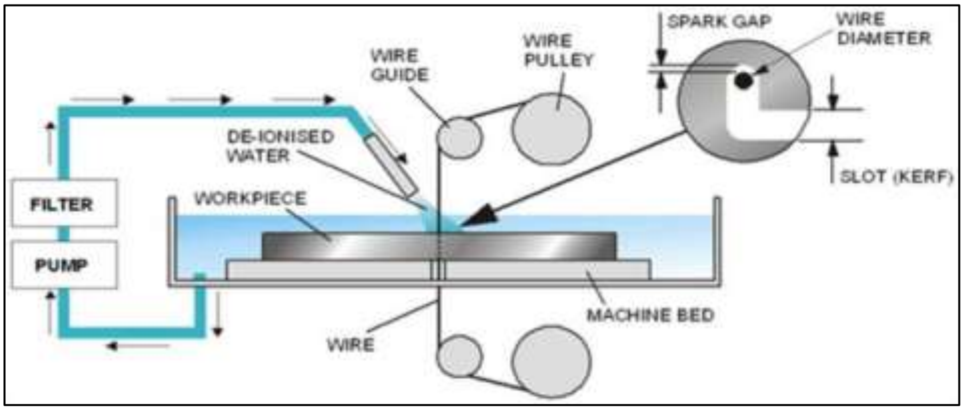

Fig. 1: Working principle of WEDM

Most of the past research work has been done mainly on rough cutting operations. The surface of the machined workpiece had poor surface integrity, micro cracks, heat affected zone were the major outcomes of the rough cutting operations [1].

Jangra et al. used the grey based Taguchi method to optimize the MRR and SR for WEDM of WC-Co composite. Results obtained by him showed that taper angle, Pulse ON time (Ton) and Pulse OFF time (Toff) parameters were most significant [2].Machining through wire-EDM, it has been shown that surface roughness increases with increased current pulse duration, peak discharge current and energy per spark.

Flushing is also important to get a better surface finish. Recast layer thickness also increases with current pulse duration and energy per spark.

Li et al have shown that the surface integrity of Inconel 718 depends directly the discharge energy density during WEDM process [3]. For the high discharge energy the micro structure of the surface changed to coral reef topography and for low discharge energy density random micro voids are formed. The average recast layer thickness increases with increase in pulse energy, higher discharge current and longer duration of pulse on-time.

Kahng and Rajkumar observed that with higher discharge a deeper HAZ and along with deeper cracks [4].

Khan investigated the electrode wear and MMR during the EDM process. They found that lower thermal conductivity material causes higher wear and MMR during the EDM as they have less tendency to dissipate heat energy into the electrode [5].

The recast layer thickness is mainly influenced by the Pulse ON duration. As the Pulse ON time increases the recast layer increases, and if cracks appear they would be micro-cracks and exist in the recast layer, initiating at its surface and travelling down perpendicularly towards the parental material [6].

The EDM is a feasible process causing surface softening at lower cutting speeds, but at higher speed caused micro damage in the surface and subsurface areas [7].

The effect of process parameters on metal removal rate, re-cast layer and surface finish was studied with statistical models of the EDM process and the Pulse current is critical factor affect the surface finish [8].The temperature distribution on the machined surface by wire EDM was the subject of a research of S. Keith Hargrove *et al* [8]. They developed a method of finite element to model the distribution of temperature in the part and to measure the thickness of the HAZ under conditions of different cutting parameters. They found that the optimal parameters reduce the HAZ thickness that they calculated from a criticized temperature, 400°C beyond the layer known as thermal affected. The minimum thickness found in this zone is 9.4µm for a tension of 4V and time of impulse 8µs. This means the smaller the tension and the time of impulses is, the finer the heat affected zone HAZ.

Rajesh Choudhary and H Kumar conducted experiment on EN-31 die steel machined by EDM. They showed that the amount of debris particles becomes too large as the discharge energy increases. This causes an electrically conductive path between the surfaces of the tool and workpiece which causes unnecessary discharge that damages the surface [9]. And also the Heat Affected Zone depends on the amount of heat available, its cooling and conduction process.

Yanzhen Zhang, and Yonghong Liu studied the formation of recast layer using different dielectric fluid. Their results showed that by using water oil emulsion as dielectric the recast layer obtained as a greater thickness and with greater surface roughness then using kerosene as a dielectric [10]. The micro cracks formed with water oil emulsion have deeper penetrations then the micro cracks obtained from water as dielectric medium.

Bhosale Sachin and Shelge Shrinivas conducted experiments on the study on recast layer formation machined by wire cut discharge machine. From the experimental results, the most influenced parameter for recast was Pulse ON, wire feed and then Pulse OFF. It was observed that, when the Pulse ON time increases while Pulse OFF decrease the recast layer thickness rapidly increases. This is due the molten materials builds up and it re solidified on the machined surface during cooling period [11]. The micro hardness of the workpiece had increased value at the cut surface then the micro hardness of the base metal, which clears the presence of recast layer after machining as it altered micro structure which results in increased micro hardness.

II. EXPERIMENTAL PROCEDURE

Figure 2 shows the experimental setup of wire cut electric discharge machine.

Fig. 2: Experimental setup of WEDM

Titanium Grade 2 is used as the workpiece material for the experiment. Parameters selected for the study are Pulse ON time, Pulse OFF time and Bed Speed.

Table – 1
Input parameters with Range

Sl. No	*Parameters*	*Range*
1	*Pulse ON (µs)*	*10-60*
2	*Pulse OFF (µs)*	*7-12*
3	*Bed Speed (µ/s)*	*100-300*

Experiment is designed using L_9 orthogonal array for 3 different independent variables and 3 levels.

Table – 2
L_9 orthogonal array with machining parameters

Sl. no	*Pulse ON*	*Pulse OFF*	*Bed Speed*
1	*10*	*7*	*100*
2	*10*	*10*	*200*
3	*10*	*12*	*300*
4	*30*	*7*	*200*
5	*30*	*10*	*300*
6	*30*	*12*	*100*
7	*60*	*7*	*300*
8	*60*	*10*	*100*
9	*60*	*12*	*200*

Nine samples are machined using WEDM, each sample having the dimensions of length 10mm, width 10mm and thickness 15mm.

The cut samples are polished with different grits 300, 500, 800, 1000 and 2000. The polished samples are electro polished to get mirror finish as shown is fig 3.

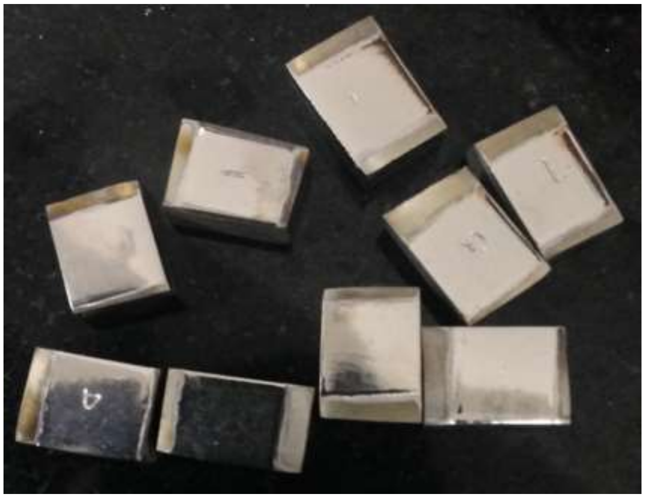

Fig. 3: Electro polished samples

After electro polishing the samples, these samples are subjected to chemical etching. Kroll (H_2O 92ml, HNO_3 6ml and HCL 2ml) is used for the etching.

For the measurement of the recast layer the chemically etched samples are analyzed in Scanning Electron Microscope.

III. EXPERIMENTAL OUTCOMES

Table 3 shows the thickness of the recast layer formed on the workpieces machined by WEDM.

Table – 3
Recast layer thickness for each samples.

Sample	*Pulse ON [μs]*	*Pulse OFF [μs]*	*Bed Speed [μ/s]*	*Recast layer Thickness [μ]*
1	*10*	*7*	*100*	*10.37*
2	*10*	*10*	*200*	*4.9*
3	*10*	*12*	*300*	*11.235*
4	*30*	*7*	*200*	*9.91*
5	*30*	*10*	*300*	*12.99*
6	*30*	*12*	*100*	*20.59*
7	*60*	*7*	*300*	*16.28*
8	*60*	*10*	*100*	*18.005*
9	*60*	*12*	*200*	*11.445*

The fig 4, 5 and fig 6 show the presence of recast layer for the samples 2, 5 and 9 respectively.

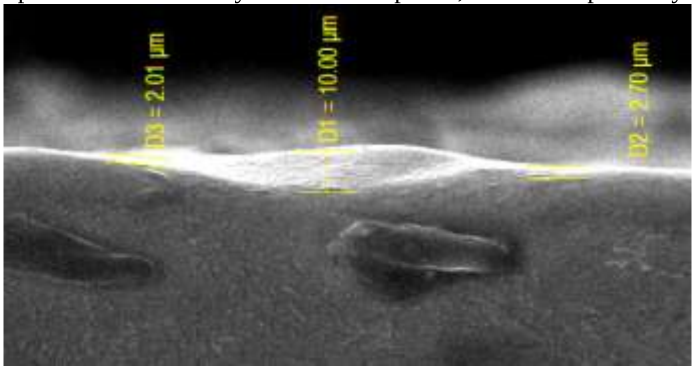

Fig. 4: Sample 2- SEM image viewed at 1000x.

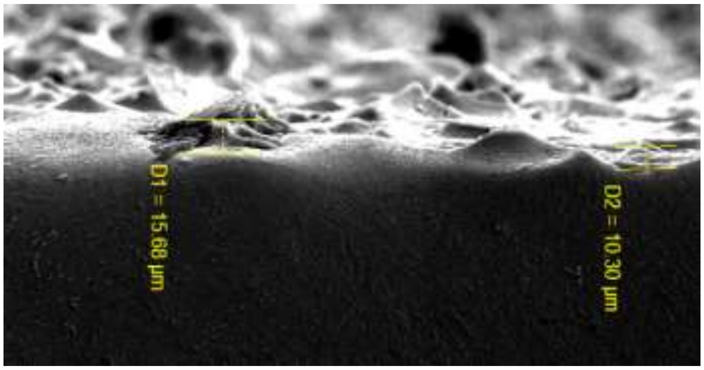

Fig. 5: Sample 5- SEM image viewed at 500x.

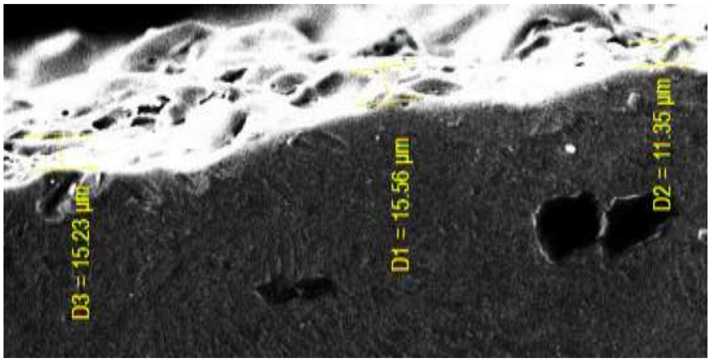

Fig. 6: Sample 9- SEM image viewed at 500x.

After the experimentation according to Taguchi's L_9 orthogonal array, the signal to noise for each recast layer thickness value is calculated using MINITAB software.

Table - 4
Signal-To-Noise ratio

Sample	*Pulse ON [µs]*	*Pulse OFF [µs]*	*Bed Speed [µ/s]*	*Recast layer Thickness [µ]*	*S/N Ratio*
1	*10*	*7*	*100*	*10.37*	*-20.3156*
2	*10*	*10*	*200*	*4.9*	*-13.8039*
3	*10*	*12*	*300*	*11.235*	*-21.0115*
4	*30*	*7*	*200*	*9.91*	*-19.9215*
5	*30*	*10*	*300*	*12.99*	*-22.2722*
6	*30*	*12*	*100*	*20.59*	*-26.2731*
7	*60*	*7*	*300*	*16.28*	*-24.2331*
8	*60*	*10*	*100*	*18.005*	*-25.1079*
9	*60*	*12*	*200*	*11.445*	*-21.1723*

From the main effect plots for S/N ratio of recast layer (figure 7) signal to noise ratio is smaller for third level of Pulse ON time (60µs), third level of Pulse OFF time (12µs) and first level of Bed speed (100µ/s).

So the optimum parameters for minimum recast layer thickness value are Pulse ON time of 60µs, Pulse OFF time of 12µs and Bed speed 100 µ/s.

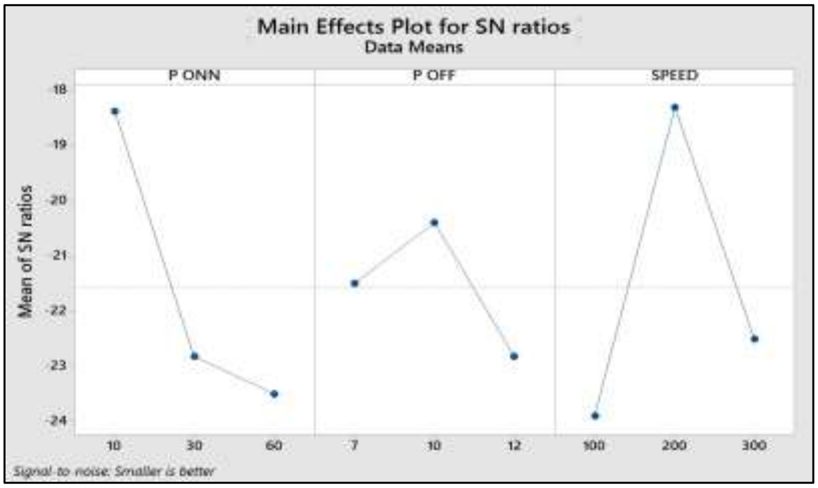

Fig. 7: Main effect plots for signal to noise ratio of recast layer

Response table can be obtained from session part of MINITAB software where all the calculations are tabulated.

Table - 5
Response table for smaller the better problem

Levels	*P ON*	*P OFF*	*Bed Speed*
1	*-18.38*	*-21.49*	*-23.90*
2	*-22.82*	*-20.39*	*-18.30*
3	*-23.50*	*-22.82*	*-22.51*
Delta	*5.13*	*2.42*	*5.60*
Rank	*2*	*3*	*1*

Form the data obtained from response table 5, it shows that the Pulse OFF time with rank 3 and Bed speed with rank 1. Which means that by Taguchi analysis it can be concluded that the Bed speed has significant effect on the thickness of the recast layer and Pulse OFF time has least effect on recast layer thickness.

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