Investigation into surface integrity of wire-electro discharge machined surface

Ketan Kokate, Vinod Jadhav, Suyash Kubal, Ayushman Dutta, Sourabh Nair, Abimannan Giridharan*
School of Mechanical and Building Sciences,
VIT University Chennai campus, Chennai - 600 127, INDIA

Abstract

Titanium alloys are widely used in automotive, aerospace and marine applications that require materials with high corrosion resistance and strength. Titanium Grade 2 (TiGr2) materials possess high corrosion resistance property and is mainly used in aircraft skin, exhaust pipe shrouds, etc. In this paper an attempt has been made to study the influence of WEDM process parameters such as pulse ON time, pulse OFF time, peak current and servo voltage on surface characteristics such as surface roughness and white layer thickness which are taken as output parameter Among these input parameters, peak current is having dominant effect on both surface roughness and white layer thickness. A mathematical model is proposed using regression analysis to identify the significant parameter that affects surface roughness and white layer thickness. The proposed model is well in agreement with the experimental results that predict the surface roughness and white layer thickness with an error of 11.21% and 3.04% respectively.

Keywords: Wire electro discharge machining, Surface roughness, White layer thickness, Regression analysis, Titanium alloy

1. INTRODUCTION

Wire electro discharge machining (WEDM) is a unique adaptation of Electrical Discharge Machining (EDM) process mostly used for machining difficult to machine materials with intricate profiles. The material removal in WEDM is by means of rapid repetitive spark occurring between the continuously travelling wire electrode (tool) and workpiece immersed in a dielectric medium (deionized water). Incidence of spark melts and vaporize both tool and workpiece material. As the discharge ceases, the rapid burst of vapour bubble ejects the molten material from the surface. The un-ejected molten material gets re-solidified as white layer or recast layer on the machine surface [1].

Several researchers have attempted to study influence of WEDM process parameters on surface characteristics viz. surface roughness and white layer of machined workpiece. Gokler and ozanozgu [2] proposed an hypothesis to identify the machining feasibility of different types of steel material using WEDM process. Williams and Rajurkar [3] studied the influence of peak current on thickness of recast layer formed during machining AISI 4340 steel surface. Authors have attempted to achieve the minimal thickness of white layer on the machined surface by varying dielectric conductivity and by increasing the number of passes during machining [4]. Hascalyk and Caydas [5] have studied the influence of WEDM process parameters on thickness of white layer during machining of AIS D5 tool steel material. Authors have also attempted to study the influence of WEDM process parameters on formation of white layer while machining advance materials such as porous metal foams, metal bond diamond grinding wheels, sintered Nd-Fe-B magnets, carbon–carbon bipolar plates and shape memory alloy [6]. Shunmugam and Kuriakose [1] made a detailed study on formation of oxide layer during WEDM machining of Ti6Al4V surface using X-ray diffractometer. Authors have attempted to study the elemental mapping of WEDM machined surface using X-ray diffractometer [7, 8]. The erosion phenomenon in WEDM is highly complex and possesses a non-linear behavior. Authors have attempted to propose hypothesis to understand the relationship between the various WEDM input parameters on machining characteristics. Many researchers have attempted to develop a model for predicting surface roughness and white layer thickness during WEDM process. Kuriakose et al [9] used a data mining approach for obtaining optimal process parameter combination for achieving better surface finish. Kuriakose and Shunmugam [10] used a Non-Dominated Sorting Genetic Algorithm (NDSGA) to predict the influence of WEDM process parameters on surface roughness of machined component. Authors proposed a hypothesis to predict surface finish of WEDM machined component using Taguchi analysis. Hewidy et al [11] attempted to propose a model using RSM for predicting surface roughness of machined Inconel 601 surface. Gauri and Chakraborthy [12] attempted to predict surface roughness of the machined component using S/N ratio. Puri and Bhattacharyya [13] proposed a model using response surface methodology to understand the relationship between white layer thickness and various WEDM process parameters. From literature it is observed researchers have attempted to study the influence of WEDM process parameters on various materials and not much work is carried out in studying the influence of WEDM process parameters on surface roughness and white layer thickness during machining of Titanium Grade 2 (pure titanium) material.

In this paper, an attempt has been made to analyze the influence of WEDM process parameters on surface roughness and thickness of white layer of TiGr2 machined surface. A model is proposed using regression analysis to predict surface roughness and white layer thickness of machined surface during WEDM process.

2. EXPERIMENTATION

Experiments were conducted on ELECTRONICA ECOCUT machine with four controllable axes. Among the various WEDM process variable, parameters such as pulse ON time, pulse OFF time, peak current and servo voltage are selected as input parameters. The effect of these parameters on white layer thickness is analyzed which is taken as the output parameter. TiGr2 is selected as the workpiece material. The chemical

* Author to whom correspondence should be made, Email: giridharan.abimannan@vit.ac.in

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composition of TiGr2 material is given in Table 1. The workpiece (50 x 45 x 10 mm) used for conduct of experiment is given in Fig. 1. The input parameters are varied at two levels and L16 full factorial design is used to conduct experiments. The influence of input parameters on white layer thickness is given in Table 2. The surface roughness of the machined components is measured using MarSurf XR20. The thickness of white layer is measured at five different locations using optical microscope and their average value is given in Table 2. A model is proposed using regression analysis to predict the most influencing parameter on surface roughness and white layer thickness.

Table 1 Chemical composition of TiGr2 material

Elements	C	Fe	H	N	O	Ti
Value	0.1	0.3	0.015	0.03	0.25	99.2

Table 2 Effect of process parameters on surface integrity

S. No.	T_{ON} (μs)	T_{OFF} (μs)	I_P (A)	SV (V)	R_a (μm)	WLT (μm)
1	20	36	1	30	2.64	15.29
2	20	36	1	60	2.75	15.62
3	20	36	2	30	2.83	15.81
4	20	36	2	60	2.93	15.92
5	24	36	1	30	2.75	16.71
6	24	36	1	60	2.84	16.79
7	24	36	2	30	3.24	18.56
8	24	36	2	60	3.39	18.50
9	20	40	1	30	2.45	21.60
10	20	40	1	60	2.59	22.67
11	20	40	2	30	2.66	22.20
12	20	40	2	60	2.72	23.06
13	24	40	1	30	2.51	21.89
14	24	40	1	60	2.59	22.96
15	24	40	2	30	2.98	22.47
16	24	40	2	60	3.04	24.45

T_{ON} – Pulse ON time, T_{OFF} – Pulse OFF time, I_P – Peak current, SV – Servo voltage, R_a – Surface roughness, WLT – White layer thickness

3. RESULTS AND DISCUSSION

3.1 Effect of process parameters on surface roughness

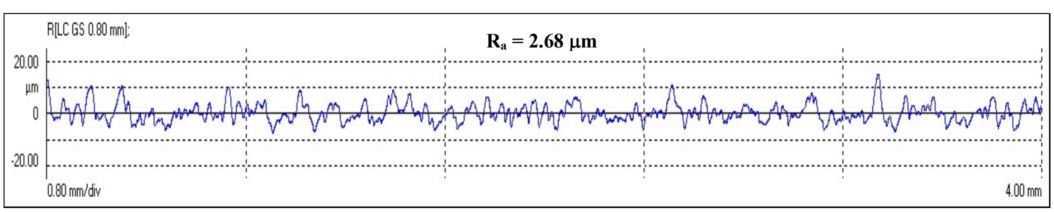
The influence of input parameters on surface roughness is given Table 2. It is observed from Table 2, increasing pulse ON time, peak current and servo voltage surface roughness increases. Increasing pulse OFF time surface roughness decreases. As the pulse ON time increases, more amount of material is removed from surface that resulted in increased surface roughness [5]. Increasing the peak current and servo voltage surface roughness of machined component increases due to increased discharge energy per spark [8]. Pulse OFF time is having in-significant effect on surface roughness compared to that of pulse ON time, pulse OFF time and servo voltage. The influence of peak current on surface roughness is given in Fig. 2.

3.2 Effect of process parameters on white layer thickness

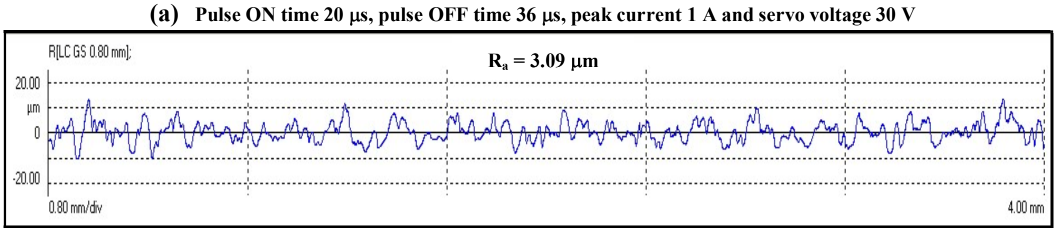
The effect of process parameters on white lyer thickness is given in Table 2. White layer thickness is affected by pulse ON time, pulse OFF time, peak current and servo voltage. As the pulse ON time increases more amount of material is melted and redeposit on the adjacent surface forming thicker white layer [14]. As the peak current is increased, the amount of material eroded per spark increases that resulted in increased white layer thickness [8]. Increasing the pulse OFF time keeping other parameters constant white layer thickness increases. As the pulse OFF time is increased, the time interval between the pulses increases. The molten material of spark gets more time to cool and gets re-solidified on the machined surface. This resulted in increased white layer thickness. Fig. 3 shows optical microscope image of WEDM machined specimen take at magnification of 200X. The influence of pulse OFF time on white layer thickness keeping all other parameter constant can be observed from this Fig. 3.

3.3 Modeling of surface roughness and white layer thickness

The mechanism of metal erosion in WEDM process is highly complex and stochastic. To have a better understanding on the effect of process parameters, an attempt has been made to develop a model for surface roughness and white layer thickness Regression analysis is performed to find out the relationship between factors and surface integrity (surface roughness and white layer thickness). In conducting regression analysis it is assumed that factors and the response are linearly



(a) Pulse ON time 20 μs, pulse OFF time 36 μs, peak current 1 A and servo voltage 30 V



(a) Pulse ON time 20 μs, pulse OFF time 36 μs, peak current 2 A and servo voltage 30 V

Fig. 2 Influence of peak current on surface roughness

related to each other. The regression equation is as follows

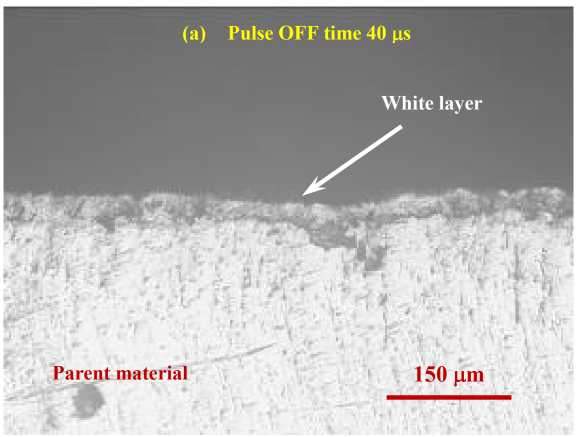
$$Y = \beta_0 - \beta_1 x_1 + \beta_2 x_2 + \cdots \beta_k x_n + C$$

In which *Y* is the response and ˇ*i* is the regresses of *i*th factor and denotes residual. The derived regression equation for roughness and white layer thickness is given in equation (1) and (2) respectively.

$$Roughness = 1.327 - 0.0572\,T_{ON} + 0.0550\,T_{OFF} + 0.3346\,I_p + 0.0033\,SV \quad (1)$$

$$WLT = -27.89 + 1.5031\,T_{ON} + 0.3175\,T_{OFF} + 0.930\,I_p + 0.0227\,SV \quad (2)$$

It is observed from the equation (1), that surface roughness is affected mostly by peak current compared to that of pulse ON time and servo voltage. Also the white layer thickness is affected by pulse ON time, pulse OFF time, peak current and servo voltage. It is observed from equation (1) and (2) the effect



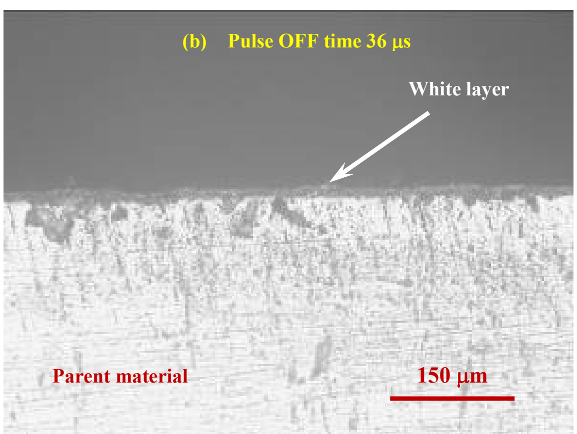


Fig. 3 Effect of pulse ON time (24µs), peak current (1A) and servo voltage (60 V) on white layer thickness

of pulse OFF time is dominant in white layer thickness compared to that on surface roughness. The regression models predicts surface roughness and white layer thickness at 88.79% and 96.96 % respectively. The interaction plot of process parameters on roughness and white layer thickness if given in Fig.4

Conclusion

The effect of input parameters such as pulse ON time, pulse OFF time, peak current and servo voltage on the output parameters such as surface roughness and white layer thickness is analyzed. The following are the important conclusion arrived

1. Surface roughness increases with increase in pulse ON time, peak current and servo voltage. The effect of pulse OFF time is negligible. Among the input parameters, the effect of pulse ON time and peak current shows dominant effect on surface roughness compared to that of pulse OFF time and servo voltage
2. White layer thickness increases with increase in peak current and pulse ON time. It is also observed that increasing pulse OFF time WLT increases. As the spark discharge ceases, the molten material gets enough time for cooling and redeposit on the machined surface.
3. The proposed regression model predicts surface roughness and white layer thickness with 88.79% and 96.96 % respectively.

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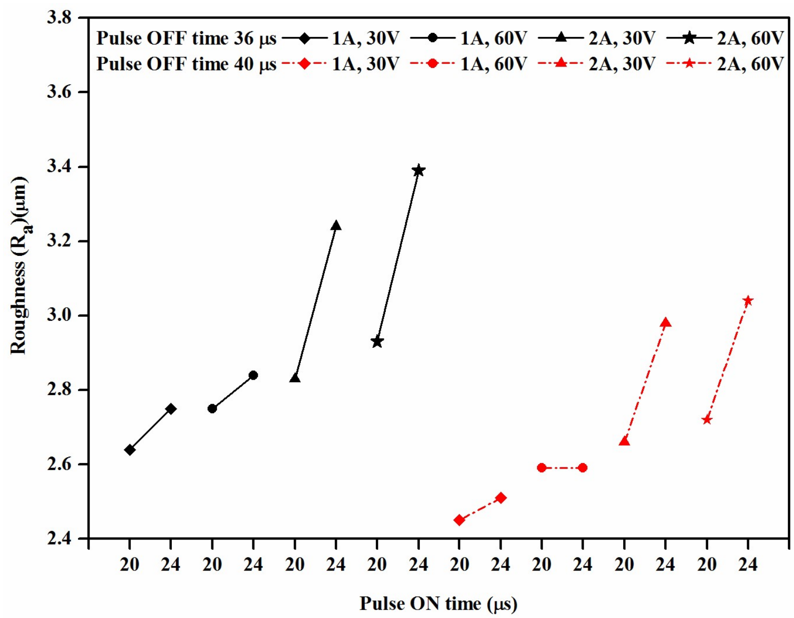
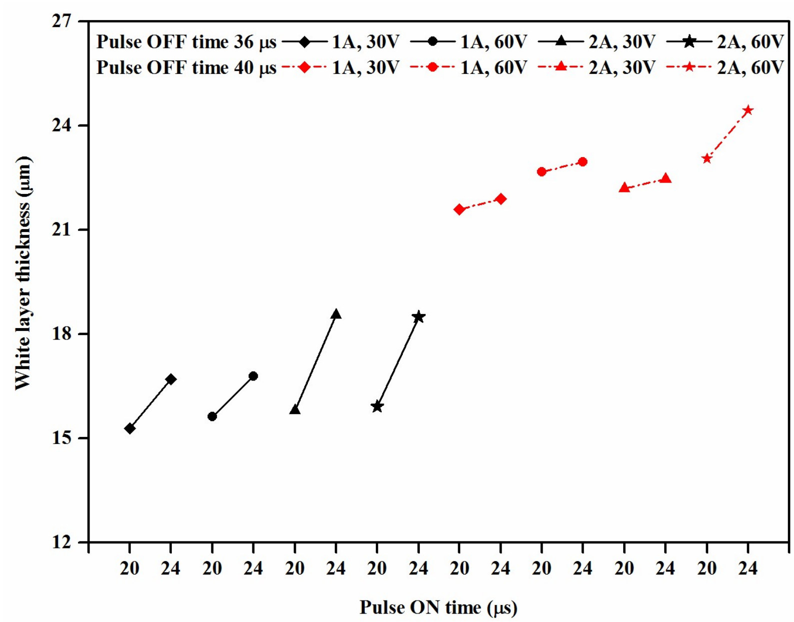


(a) Interaction plot of process parameters on surface roughness



(b) Interaction plot of process parameters on white layer thickness

Fig.4 Influence of process parameters on surface roughness and white layer thickness