Micro Topography on Tool Steel Processed using Wire Electrical Discharge Machining

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Abstract: Wire Electrical Discharge Machining (Wire-EDM) using electrical energy to cutting materials, they penetrate material not continuously instead penetrate with a specific interval that called as a pulse on time. Open voltage is a variable to control value of penetrate energy. Material removal rate caused melted and evaporation work piece material. Flushing by dielectric fluid affected quenching on the surface machined materials. During Wire-EDM process, re-heating of melted material. Constant quenching and re-heating also caused the craters to be relatively deep and width on a microscale. That's craters affected has impact on surface roughness on macro scale. In Wire-EDM process, surface roughness is important to describe deviation characteristic on surface of workpiece. A research conducting to observe micro topography by using variable pulse on time and open voltage, including surface roughness on tool steel surface who has processed using Wire-EDM. This research using design experiment factorial 3x3. Surface roughness measurement conducting using Mitutoyo surftest. Surface electron measurement (SEM) used to observe micro topography on workpiece surface. From this research we can conclude that pulse on-time and open voltage directly proportional to surface roughness response variable. From this research was achieve lowest surface roughness 1,33 μm on combination pulse on time 2 μs and open voltage 75V and the highest surface roughness 2,52 μm on combination pulse on time 6 μs and open voltage 105V.

1 INTRODUCTION

Although equipped with advanced technology conventional machining processes, still insufficient to process high hardness material and complex contours which cannot be complete with conventional machining processes. To solve the problem, the machining industry is now wide applied non-conventional machining processes. Wire-EDM process is one of nonconventional machining who use electrical energy to produce sparks between anode and cathode, then convert spark into thermal energy with temperature about 8.000^{o}C to 20.000^{o}C (Kutuzova & Melnik, 2018). Current penetrate from electrode to workpiece with frequency about 20.000 Hz to melting 30.000 Hz, it made both melting and evaporating (Jaiswal, Peshwani, Shivakoti, & Bhattacharya, 2018). During Wire-EDM process, cutting process not conducted continuously. It come since pulse on-time phase and stop when it entering pulse off-time phase (Liu et al., 2017). During Wire-EDM process, the cutting process not conducted continuously. It come since pulse on-time phase and stop when it pulse off-time phase. It might to avoid wire rupture caused stress during machining process (Calvo, Daniel, Calvo, & Daniel, 2020).

Wire-EDM applied on industrial since 1950 (Bravo et al., 2018) and has continuous development technology, the current research has asynchronous control mode to meet Industrial 4.0 requirement (Zhou, Jing, Yang, Yao, & He, 2018). It has an ability to processing mechanical part who require complex shape, high precision and low surface roughness (Zhou, Wu, Xu, Mu, & Dou, 2018). There is wide application of Wire-EDM including aerospace, nuclear, automotive, tools, jewellery, mould, dies, and also medical equipment industries (Wälder et al., 2018). Wire-EDM have a capability to process hard materials more effective than conventional machining process, those materials such as titanium, nimonic alloy, and zirconium. But, Wire-EDM machining process has their own problems such as

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forming of micro heat affective zone (HAZ), recast layer, micro-crack, porosity, local hardening or annealing, grain growth and forming of alloy incidentally because element transfers phenomena from wire or dielectric, its might new alloy formed on recast layer (Soundhar, Zubar, Thariq, Haji, & Sultan, 2019).

On this research Buderus 2080 tool steel applied as material specimen. This material has high resistance against wear, stability on heat treatment. It wide applied on industrial manufacture, it is common being material to make deep drawing dice, shearing blade, broaching tool, sand blasting nozzle, trimming dies and plastic mould. Buderus 2080 tool steel has chemical composition Carbon about 1.90-2.00%. Silicon about 0.20-0.30%. Manganese about 0.25-0.30% Chromium about 9.80-12.00%. Based on carbon composition, this material classified as high carbon steel. High carbon steel is strong but brittle, to improve mechanical properties by applied heat treatment such as austenizing, quenching, and tempering (Jatti, 2018). Tempering can transform their grain be martensite, then make material not just hard but also ductile. This process cover the original material disadvantage (Kou & Han, 2018).

The aim from this research is to observe influence from parameters pulse on-time and open voltage to surface roughness and micro topography on Buderus 2080 tool steel using Wire-EDM.

2 METHODS

On this research Wire-EDM using CHMER CW 32GF. Movement direction followed by five axis (x, y, z, u, and v) Wire diameter holder 0,15–0,30 mm. Maximum wire cutting 250 mm/second. Table dimension 600 mm x 400 mm. Before cutting process using wire EDM, each specimen had heat treatment to reduce stress and increase hardness. Specimen has dimension length 200 mm, width 30 mm and depth 15 mm. Specimen cutting began from left side for 10 mm with distance of each specimen about 5 mm. After all cutting process complete and cutting length for each experiment has measured, cut material 5mm perpendicular from first cutting edge.
Aquadestilata applied as dielectric during machining process. Parameter based on recommendation from manual book of material. This research runs based on flowchart that shown on Figure 1.

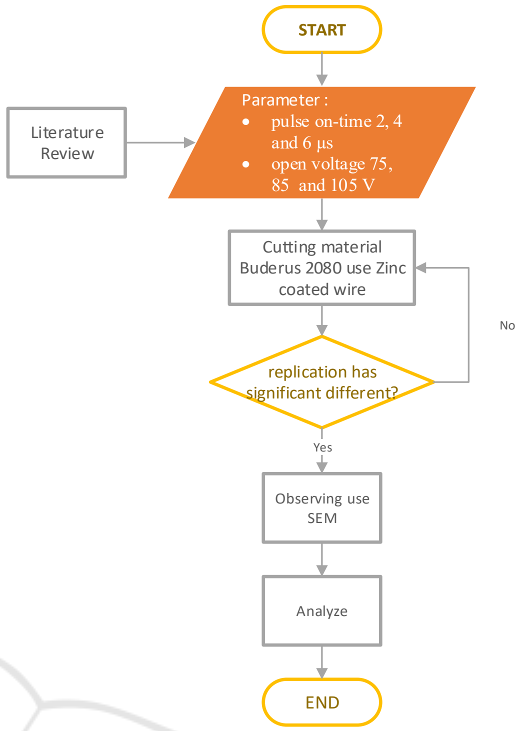

Figure 1: Research flowchart.

2.1 Material

This research using Buderus 2080 tool steel had heat treatment before. The Heat treatment process shown on Table 1. During heat treatment specimen hardness increased from 55 HRC to 60 HRC.

Table 1: Specimen Heat Treatment Process.

Process	Temp (ºC)	Time (minute)
Soft Annealing		
Stress Revealing		
Preheating	600	45
Preheating II	850	45
Austenizing	960	45
Quench Media	-5	Sudden
Tempering I	180	120
Tempering II	180	120
Tempering II	180	120
Carburizing		
Nitro Carburizing		

Wire electrode using AC CUT VS 900 zinc-coated brass wire with chemical composition Cu about 65% and Zn about 35%. Wire tension 880 N/sq.mm. Elongation 2%. Tolerance about ± 0.001 mm.

2.2 Measurement

Surface roughness measurement perpendicular to wire cutting direction on workpiece. Mitutoyo surftest 301 use to observe surface roughness dan Scanning Electron Microscope (SEM) using to observe micro topography on workpiece. Cutting direction scheme by electrode and direction with position of surface roughness shown on Figure 2.

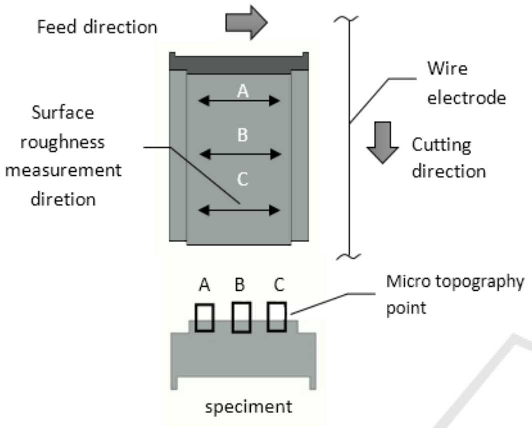

Figure 2: Cutting direction scheme and surface roughness measurement on speciment.

From Figure 2 we can see there is three point of data collectin fron surface roughness, that collecting data to observe is there any different surface roughness value from each points. Image of micro surface topography captured using 2000x zoom Scanning Electron Microscope. Potition of micro surface topography position shown on figure 1 below showed with black box. This to observe is there any different from begining, midlle and end of material cutting.

2.3 Parameters

This research using design experiment factorial 3x3 because there is two process variable, they are pulse on-time 3 level (2 µs, 4 µs and 6 µs) and open voltage 3 level (75 V, 85 V and 105 V). Constant variable on this research are:

- Low power (10 DCEN)
- Arc off time (13 µs)
- Feed rate override (9mm/s)
- Wire tension (8 g)
- Wire feed (10 mm/s)
- Water Flow (6 kg/cm^2)
- Feed rate mode (0 servo)
- Feed rate (1mm/s)
- Arc on time (2 A)
- Off time (12 µs)
- Servo voltage (50V).

Because with this design experiment we had many parameters using less materials. This research using two replications for surface roughness and surface micro topography on specimens, because we want make sure there is no significant different in one parameter. Surface rouhness data collecting using Mitutoyo Surftest 301.

3 RESULT AND DISCUSSION

The implementation of research conducting with combination variable pulse on time and open voltage on wire EDM machining. Both process variable has significant influence to surface roughness Experiment result based on design experiment factorial 3x3 shown Table 2.

Table 2: Experimental Data of Surface Roughness.

Pulse on time (µs)	Open voltage (V)	Surface roughness (µ)			Average
		Point A	Point B	Point C	
2	75	1,33	1,35	1,31	1,33
2	90	1,47	1,43	1,56	1,48
2	105	1,65	1,63	1,67	1,65
4	75	1,73	1,65	1,69	1,69
4	90	1,91	1,83	1,89	1,87
4	105	2,10	2,03	1,99	2,04
6	75	2,01	2,20	2,04	2,08
6	90	2,28	2,19	2,29	2,25
6	105	2,50	2,49	2,31	2,43
2	75	1,42	1,39	1,37	1,39
2	90	1,42	1,67	1,65	1,58
2	105	1,83	1,71	1,73	1,75
4	75	1,77	1,80	1,78	1,78
4	90	1,78	1,81	1,72	1,77
4	105	2,18	2,04	2,20	2,14
6	75	2,20	2,18	2,17	2,18
6	90	2,12	2,16	2,19	2,15
6	105	2,45	2,61	2,52	2,52

3.1 Influence Pulse on Time and Open Voltage to Surface Roughness

Experiment result data statistically tested to determine which process variable has a significant effect on the response variable. Analysis of variants (ANAVA) used to identified is there variables pulse on-time and open voltage has affected significantly to surface roughness response. Variable pulse on-time and open voltage have significant inluence to surface roughness response shown on Table 3.

Table 3: Result from Table ANAVA.

Source	DF	SS	MS	F
Pulse on time	2	1,64431	0,82216	68,98
Open Voltage	2	0,37788	0,18894	14,62

From Tabel 2 determined there is pulse on time factor have significant influence to seuface roughness on speciment, this value 68,98 % if comparing with open voltage 14.62%. Surface plot for each variable shown on Figure 2. Statistically pulse on time is a dominant variable.

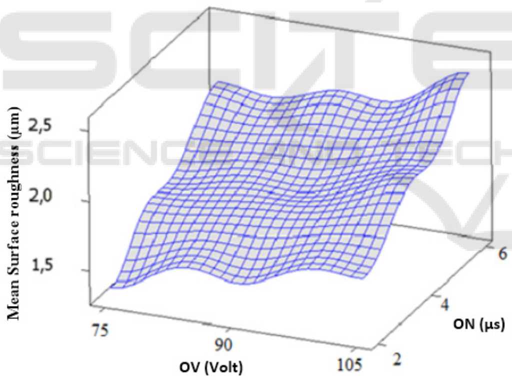

Figure 3: Surface plot ANAVA from each variable.

From surface plot on figure 2 shown incresing in pulse on-time variable and open voltage will increaing surface roughness value.

Beside ANAVA test we conducted Tukey Test, it to determine level from each variable Pulse on Time and Open Voltage who influence to surface roughness. Table 4 show result from Tukey test on Pulse on Time variable.

Table 4: Result from Table ANAVA.

Pulse on Time (µs)	N	Mean	Grouping
6	6	2,3	A
4	6	1,9	B
2	6	1,5	C

Result of Tukey test on table 4 show different result of surface roughness from pulse on time parameters are different. The lowest mean value (1,5) on pulse on time 2 µs and highest mean value (2,3) on pulse on time 6 µs. Statically increasing on pulse on time will affected on surface roughness. Based on this test we can conclude pulse on time variable is directly proportional to surface roughness. Tabel 5 show result from Tukey test on Open Voltage Variable.

Table 4: Result from Table ANAVA.

Open Voltage (V)	N	Mean	Grouping
105	6	2,1	A
90	6	1,9	B
75	6	1,7	C

Like Table 4 result of Tukey test on table 5 show different result of surface roughness from Open Voltage parameters are different. The lowest mean value (1,5) on Open Voltage 75V and highest mean value (2,1) on Open Voltage 105 V. Statically increasing open voltage will affected on surface roughness. Based on this test we can conclude pulse on time variable is directly proportional to surface roughness, but Pulse on Time has more significant volume than Open Voltage. It shows that result of surface roughness is different at the three different Open Voltage levels. Analysis of variance requires that the residuals must meet three assumptions; identical, independent and normality distributed with zero mean with a certain variance.

Result of identical test show on figure 4

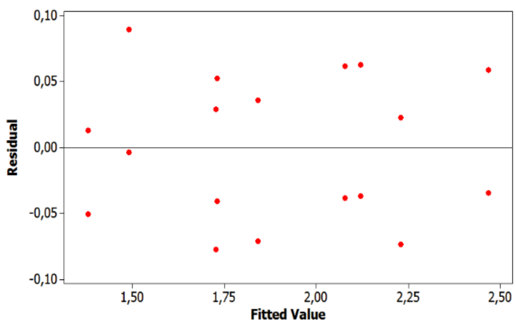

Figure 4: identical test diagram.

Figure 4 shows that the residuals (marked with re dots) are randomly distributed around the zero line and not form a specific pattern. Thus the identical residual assumption is fulfilled. this shows that all data are different

Independent test on this research conducted using auto correlation function (ACF). Based on ACF show on figure 5, there is nothing ACF value lag out from interval. This proves that there is no correlation between residuals, meaning that the residuals are independent.

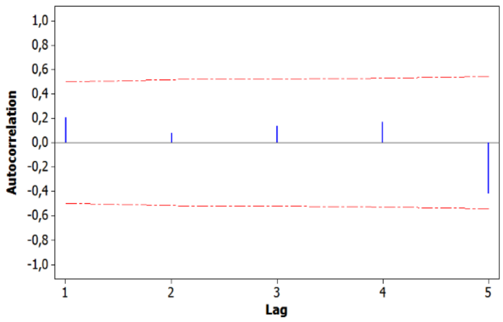

Figure 5: Plot ACF on surface roughness respons.

Residual normality test residual conducted using Kolmogorov-Smirnov test. Hipotesis that applied are:

H_0 : Residuals are normally distributed

H_1 : Residuals are not normally distributed

H_0 rejected if p-value less than $\alpha = 0{,}05$. Result of normality test show on Figure 6.

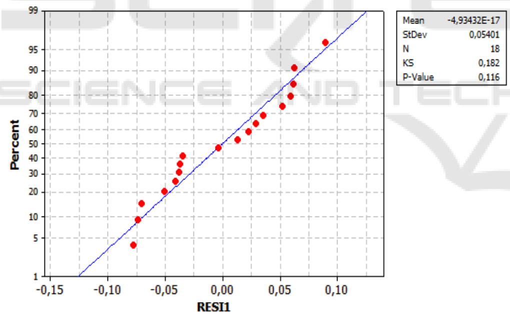

Figure 6: Plot of normality distribution test on surface rouhness response.

From Kolmogorov-Smirnov test conclude:

- p-value 0,116 it mean bigger than $\alpha = 0{,}05$. Therefore, it can be concluded that H_0 failed to be rejected or that residuals were normally distributed.
- Mean value about -4,9343x10-17 it mean very small and close to zero.
- Variance on residual is about (0,182)2 = 0,03312

Thus the assumption of a normally distributed residual with a mean value equal to zero (or close to zero) and having a certain variation (amounting to 0.03312) has been fulfilled. Graphically, the relationship between the Pulse on Time and Open Voltage factors in the Wire EDM machining process to the surface roughness response is shown in Figure 7.

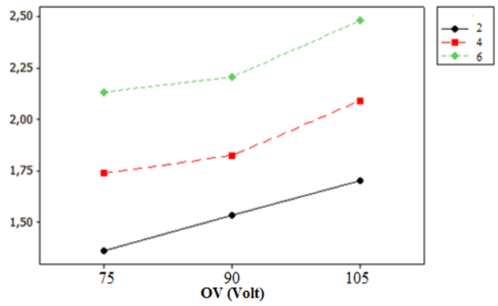

Figure 7: Plot graphic influence factor Pulse on Time and Open Voltage to surface roughness.

A fter passing, identical, independent and normality test. It can be concluded that the pulse on time and open voltage have an influence on the surface roughness statistically. phenomena can be explained that high pulse on-time lead to consequence a phenomena called “double sparkling” and higher local spark, it confirmed by another research (Nur, Muas, & Risal, 2019) (Dabade & Karidkar, 2016). Double sparkling come while high pulse on time, it might produce higher frequency of spark. That spark penetrates to work piece then followed with next spark briefly. a higher pulse on-time make frequency of thermal energy who transferred on work piece get higher (Degenhardt, Stief, Dantan, Etienne, & Siadat, 2018). It leads to heat transfer from out surface of workpiece to next layer (Klocke, Welschof, Herrig, & Klink, 2018). That heat transfer conducted deeper, then more work piece will erode. Work piece erode randomly on a length cutting area, there deviates from linear reference. If deviation got higher, it will have affected on surface roughness value. Double sparkling phenomena appear on pulse on time 4 µs and 6 µs. High open voltage parameter causes a voltage between work piece and wire electrode be higher. Voltage bring out to a discharge. High discharge energy, followed by increasing thermal energy transferred to work piece. That will erode work piece and lead to material removal. On micro scale it brings out a crater on surface of work piece. Increasing of thermal energy who transferred from workpiece forming deeper crater (Özerkan, 2018) (Marelli, Singh, Nagari, & Subbiah, 2020).

3.2 Micro Surfae Topography on Work Piece

Globule is a part of molten metal, it spotted on surface of work piece randomly. Globule formed by trap gas and stack up on material and quenched by dielectric during machining (Kou & Han, 2018). Pockmark formed by erosion material during machining, then turn out concavity profile like crater on surface of workpiece. During machining process there current between wire electrode and materials, it leads to spark. That spark penetrates on workpiece, then performed craters on workpiece. Debris is part from workpiece and spreads eroded during machining process. Bouncing out Material and re-attaching from workpiece because laminar wave performed by electrode flushing (Jagtap, 2018). Figure 8 to 10 is image result processing using SEM with 2000x.

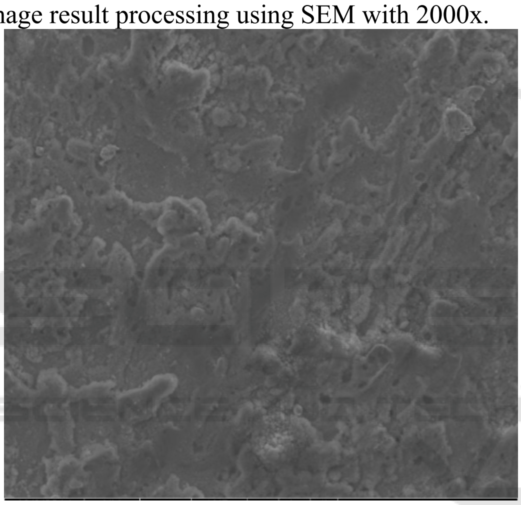

Figure 8: Micro surfaec topography on workpiece with combination parameters 2μs and open voltage 105 V.

Figure 8 shown micro-topography performed by pulse on-time 2 μs and open voltage 105 V, from this combination formed rare pockmark, but have large diameter pockmark. Current from discharge erode work piece during machining process. Diameter size of pockmark and current are directly proportional, it means the highest current lead to a large diameter of pockmark. On this combination founded a few globules.

Figure 8 show pockmark and crater spotting rare and with small diameter comparing from figure 4. On this figure show surface micro-topography on workpiece combination parameters 6μs and open voltage 105 V. Observing on figure show surface from work piece covered by pockmark as long as surface of material, but with small diameter pockmark. Many globules formed and concentrate in specific area. There is much crater formed on material surface on this combination. Surface of workpiece spotting debris. Much pockmark and spread on surface of materials phenomena, caused by high pulse on-time on this combination. As a consequences spark penetrate to materials with high frequency, then more material eroded. Open voltage and discharge are directly proportional. Low discharge makes penetrate on material shallow, then forming low depth of pockmark. By and large that open voltage is a variable that influencing size of pockmark, pulse on-time is variable influencing number of pockmarks.

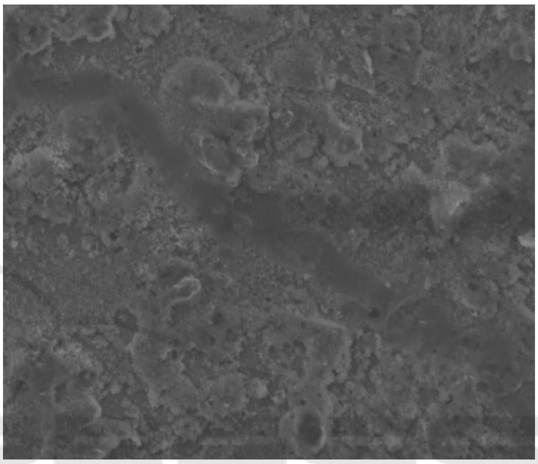

Figure 9: Micro surface topography on workpiece with combination parameters pulse on-time 2 μs and open voltage 75 V.

Figure 9 show that pockmark covered major surface of material and have big size comparing to figure 8. From this image visibly large diameter crater formed.

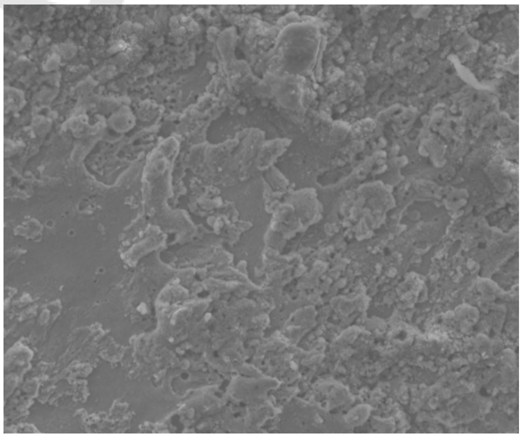

Figure 10: Micro surfaec topography on workpiece with combination parameters pulse on-time 2 μs and open voltage 75 V.

Figure 10 shown surface micro topography with 6000 x zoom from variable pulse on time 6us and open voltage 105V, visible presence of micro-crack on surface. It impact of double spark, it make spark penetrate twice simultaneously, followed by flushing. These event like quenching. From this image deep crater visible.

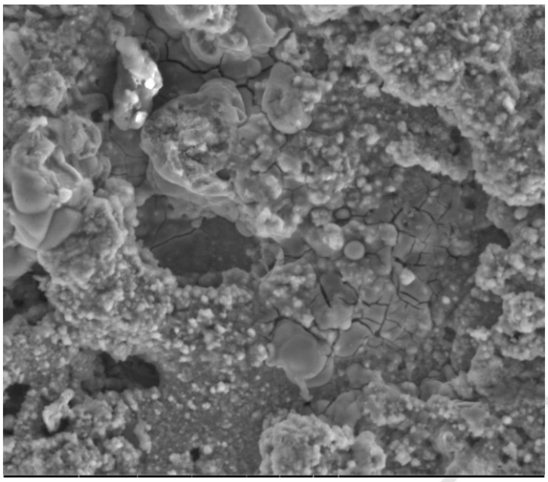

Figure 11: Micro crack visible on 6000x scale.

4 CONCLUSIONS

On wire-EDM machining, variable pulse on-time set frequency from cutting phase. Open voltage variable set value energy consumption during cutting process. On micro scale high pulse on-time increasing number of pockmark and crater, high open voltage increasing size of pockmark and crater. Number and size of pockmark and crate influencing surface micro topography on work piece. Profile of micro topography influencing surface roughness of work piece on macro scale. Surface roughness parameters are widely used to identify surface characteristics. Because the surface roughness value is more sensitive detecting changes that occur in machining process. Thus, if there are signs of increasing surface roughness then quick taking prevention. The results of statistical analysis of experimental data show that surface roughness increases with increasing Pulse on Time then Open Voltage value.

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