EFFECT OF ELECTRIC DISCHARGE MACHINING PROCESS PARAMETERS ON TITANIUM SUPER ALLOY

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Abstract: Electric Discharge Machining (EDM) is the unconventional machining process used for the machining of hard materials which cannot be machined on the conventional machining process and complicated profiles can also be obtained. The metal is removed by erosion process in all types of electro conductive materials. The eroded material on the surface of work piece and the tool is flushed away from the machined surface by the dielectric fluid. The objective of present work is to study the influence of input parameters on the machining output characteristics. The output characteristics considered are Metal Removal Rate (MRR), Tool Wear Rate (TWR), Surface Roughness (SR) and input parameters taken for the study are peak current, pulse on time, pulse off time and tool lift time for conducting the experiments on Titanium super alloy with copper Tool electrode on electric discharge machine. The experiments are conducted by varying one input parameter and keeping other input parameters constant. The results shown that the MRR, TWR and SR increase with increase in current but at 18A tool start melting. With pulse on/off time MRR and TWR increases initially and there after decreases.

Keywords: **Electric discharge machining, Metal removal rate, Tool wear rate, surface roughness, Titanium super alloy, Input parameters.**

1. INTRODUCTION

The growth of industrial and technological developments, the harder and difficult to machine materials have been developed, which find wide application to produce dies and moulds. It is also used for finishing parts for aerospace nuclear engineering automotive industry and surgical components. **K.H. Ho and S.T. Newman [1**] reported EDM as a best machining option for manufacturing geometrically complex or hard material parts that are difficult-to-machine by traditional machining processes. The non-contact machining techniques have been continuously developing in a simple tool and die making process to micro-scale applications. In recent years, EDM researchers have developed a number of ways to improve the effective sparking including some experimental concepts to improve material removal rate. This paper explores that the research work carried out from the inception to the development of die-sinking EDM in the past decade. It was reported on the EDM research relating to improvement of performance measures, the process variables optimization and controlling and monitoring the sparking process by simplifying the electrode design and manufacture. Some of the EDM applications are highlighted together with the development of hybrid machining processes. The final part of the paper was discussed these developments and outlines, the trends for future EDM research.

Anand Pandey and Shankar Singh [2] reviewed on research trends in Electrical Discharge Machining. He reported the present manufacturing industries are facing challenges from advanced materials such as super alloys, ceramics, and composites, that are hard and difficult to machine, surface quality and requiring high precision which increases machining cost. To meet these challenges non-conventional machining processes are being employed to achieve higher metal removal rate, better surface finish and greater dimensional accuracy with less tool wear. EDM machining process has a wide applications in automotive, defense, aerospace and micro systems industries plays an excellent role in the development of least cost products with reliable quality assurance. They have discussed different type of EDM processes like Die sinking EDM, Wire EDM, Micro- EDM, Dry EDM, Rotary disk electrode electrical discharge machining (RDE-EDM). They had summarized, EDM has resulted out as most cost effective and precision machining process in recent years. The contribution of EDM has brought improvements in the surface finish of advanced engineering materials. Powder mixed EDM and Ultrasonic assisted EDM has reduces tool wear and increases material removal rate. Modeling and optimization of electrical and non electrical parameters in EDM improved in precision machining of work materials.

M. Kunieda, B. Lauwers, K. et. al [3] reported the development of EDM technology by interrelating achievements in fundamental studies on EDM with newly developed advanced application technologies. Even though gap phenomena in EDM are very complicated and hence yet to be well understood, improvements in computers and electronic measuring instruments are contributing to new inventions and discoveries in EDM technology. Such newly acquired knowledge sometimes raises questions on the validity of the established theories of EDM phenomena. EDM processes involve transient phenomena occurring in a short period of time in microseconds and in a narrow space in micrometers. These EDM phenomena are not in thermal equilibrium, but include transitions between solid, liquid, gas and plasma, chemical reactions, mass transfer and displacement of boundaries. Hence, compared to other discharge phenomena such as arc discharge in welding processes, physics involved in EDM processes are obviously most complicated, observation and theoretical analysis extremely difficult. Though, it is a long way to understand completely. Advancements of various surface analyzing equipments, microscopes, high-speed imaging devices, and software tools for numerical analysis made fundamental studies progressing step by step and some of the common EDM knowledge which has been accepted for a long time are being modified.

Michael F. W. Festing [4] published a paper on guidelines for the Design and Statistical Analysis of Experiments. An experiment is a procedure for collecting data in order to answer a hypothesis, or to provide theme for generating new hypotheses and differs from a survey because the scientist has control over the treatments. Most experiments can be classified into one of formal designs; the most common is completely randomized and randomized block designs. Some experiments involve a single independent variable, whereas other involves factorial designs simultaneously vary two or more independent variables. Factorial designs often provide well additional information at little extra cost. To avoid bias experiments need to be carefully planned and to provide for a valid statistical analysis. Basically all experiments need some sort of statistical analysis in order to take account of variation among the experimental factors. Parametric methods using the t-test or analysis of variance are powerful than non-parametric methods, provided the underlying valid assumptions of normality of the residuals and equal variances. In some industries EDM is an essential operation in several manufacturing processes, which gives importance to variety, precision and accuracy. Researchers have attempted to improve the performance characteristics such as the material removal rate, surface roughness, cutting speed, and dimensional accuracy. Because of its complex and stochastic in nature and more number of variables involved in this operation the full potential utilization of this process is not completely solved.

Scott et. al [5] developed mathematical models to predict MRR and surface finish for machining D-2 tool steel at different conditions of machining. It was noticed that there was no single combination of levels of the different factors under all circumstances can be optimal. **Spedding and Wang [6]** developed models for cutting speed and surface roughness of EDM process based on the response-surface methodology and artificial neural networks (ANNs) and attempted further to optimize the surface roughness and the artificial neural networks used to predict the process performance. **Hsue et. al [7]** investigated a useful concept of discharge-angle and presented a systematic analysis for MRR in corner cutting. Discharge-angle and MRR dropped drastically to a minimum and then recovered to the same level of straight-path cutting gradually. The amount of the drop at the corner was dependent on the angle of the turning corner. The drastic variation of sparking frequency in corner machining could be interpreted as the sign of the sudden change of MRR. The sudden increase of gap-voltage might also be interpreted as the result of abrupt drop in MRR. In this paper the influence of the current, pulse on time, pulse off time and tool lift time on the output parameters MRR, TWR and SR are studied.

2. Experimental Setup

2.1 Machine Tool

Experiments were carried out on Askar microns V3525 die sinking Electric discharge machine with servo head constant gap voltage, positive polarity, in which the Z-axis is servo controlled and X and Y axis are manually controlled. All three axes have accuracy of 5µm. Experiments were carried out by pulse arc discharges generated between tool (copper) and work piece (Titanium alloy). The downward movement of electrode towards work piece is controlled by servo control mechanism, which maintains uniform gap between work piece and electrode in EDM. Commercial graded standard (EDM30 grade) oil is used as dielectric medium for flushing purpose. Side flushing has been used during all experimental runs.

2.2 Details of work piece and tool materials

Titanium based super alloy has been used as work piece. This material has excellent creep-rupture strength at high temperatures and has excellent mechanical and metallurgical properties this alloy extensively used in gas turbines, rocket motors, spacecraft, nuclear reactors, pumps and cutting tools. Titanium alloy is one of the most difficult material to machine on the conventional machine. This difficulty in machining is attributed to its ability to maintain hardness at elevated temperature this is very useful for hot working environment. This alloy has attracted many researchers due to its increasing applicability in high temperature conditions. The available research data in the form of papers and books pertaining to EDM of titanium super alloy is limited. The chemical compositions and mechanical properties of Titanium super alloys are shown in Table 1. Details of work piece are given below.

- Work piece size : 50×30 mm^2
- Work piece shape : Rectangular
- Work piece thickness : 6 mm
- Angle of cut : Vertical
- Location of work piece : Centre (on work table)
- Stability : Servo control
- Tool electrode material: Electrolytic Copper (99.9%)
- Polarity : Straight polarity (work piece negative, tool positive)

Table 1. Chemical compositions of Titanium alloy

Element	% by weight	Element	% by weight
Aluminium (Al)	5.5-6.8	Silicon (Si)	<0.15
Carbon (C)	< 0.13	Iron (Fe)	< 0.3
Molybdenum (Mo)	0.5 – 2.0	Phosphorus (P)	0.8-2.5
Vanadium (V)	0.3	Titanium Ti	balance
Zirconium(Zr)	1.5-2.5		

Electrolytic copper electrode (99.9%) has been used as tool material. The circular cross sectional area of tool electrodes has been taken to carry out the experiments. The area of circular shaped electrode was taken 113.04 mm^2 in machining. For the pilot experimentation the input parameter levels for current, pulse on time, pulse off time and electrode lift time are chosen as shown below table 3 The work piece, tool and the machined work piece are shown in figures 2 and 3.

Table 3. Input parameters and their levels

Parameter	Levels						
Current (A)	3	6	9	12	15	18	21
Pulse On Time(µsec)	5	10	20	50	100	200	500
Pulse Off Time(µsec)	5	10	20	50	100	200	500
Tool Lift Time (µsec)	5	10	20	50	100	200	500

3. Response Characteristics

The detailed discussions related to the measurement of EDM experimental parameters Metal Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (SR) are presented in the following. Metal removal rate is the amount of material removed from the work piece during the machining process of EDM due to the material erosion process. It is a desirable characteristic and it should be as high as possible to give least machine cycle time leading to increased productivity. In the present study MRR is a measured using Digital weighing balance machine and is given quantitatively in mg /min. Tool wear rate is undesirable characteristic and it should be as low as possible to give least machine cycle time leading to increased productivity. In the present study TWR is a measured using Digital weighing balance machine and is given quantitatively in mg /min. Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may be formed due to erosion. Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if small, the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface.

The parameter mostly used for general surface roughness is Ra. It measures average roughness by comparing all the peaks and valleys to the mean line, and then averaging them all over the entire cut-off length. Cut-off length is the length that the stylus is dragged across the surface; In this work the surface roughness was measured by Handy surf, which traces the surface of various machined parts and calculates the surface roughness based on roughness standards, and displays the results in µm. The work piece is attached to the detector unit of the Handysurf, which traces the minute irregularities of machined surface on the work piece surface. The vertical stylus displacement during the trace is processed and digitally displayed on the liquid crystal display of the Handysurf.

3.1. Measurement of Response characteristics

Material removal rate, Tool wear rate and Surface roughness have been used to evaluate machining performance. The MRR and TWR are calculated by measuring the weight difference of work piece and electrode, before and after machining using a digital weighing balance of type AY220 with precision 0.001mg and was calculated by using following equations.

$$MRR = \frac{(\mathrm{wp}_1 - \mathrm{wp}_2)}{T}\ mg/min$$

Where MRR is Metal removal rate, wp1 and wp2 are the weights of the work piece before and after machining, T is the machining time.

$$TWR = \frac{(wt1 - \mathrm{wt2})}{T}\ mg/min$$

Where TWR is Tool wear rate, wt1 and wt_2 are the weights of the work piece before and after machining, T is the machining time. The composition of the work piece is given in table.1. Surface roughness was measured by contact type stylus based surface tester handy surf. The centre line average (CLA) surface roughness parameter Ra was used to quantify the surface roughness.

Fig. 2 Work piece and Tool

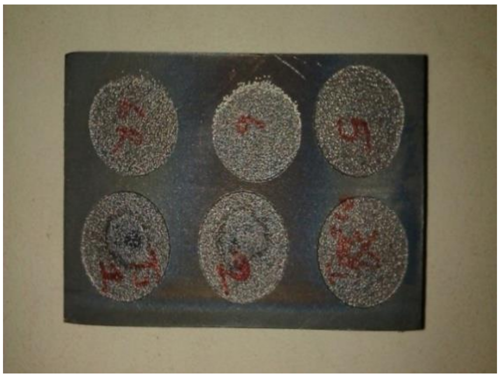


Fig. 3 Machined Work Piece

4. Experimental Results and Discussion

Experiments were conducted on the Titanium super alloy by varying four input parameters on EDM machine from minimum to maximum value and varying one parameter at a time. The output responses like metal removal rate, tool wear rate and surface roughness are obtained from the experiments. The levels of the factors are selected based on the machining condition. The effect of each parameter response characteristics are discussed in following sections. In conducting experiments the peak current is varied from 3 Ampere to 21 Ampere in steps of 3 Ampere and the other parameters remains constant (T_{on} = 10 µSec, T_{off} = 50 µSec, Gap voltage = 32 volt, Tool lift time = 20 µSec, down tine =20 µSec). The pulse on time (T_{on}) is varied from 5µsec to 1000 µsec, while the values of other parameters are kept constant (T_{off} = 50 µSec, I_p = 15 ampere, Gap voltage = 32 volt, Tool lift time=20µSec, down time =20 µSec). The results showed in table **4.6** and figures **4.8, 4.9, 4.10.** The pulse off time (T_{off}) is varied from 5µsec to 1000 µsec. The values of the other parameters are kept constant (Ton = 20 µSec; Ip = 15 Amp; Gap voltage = 32 volt; Tool lift time = 20 µSec; down tine =20 µSec). The observations from the results shown in table **4.7.** The Tool lift time is varied from 5µsec to 1000 µsec. The values of the other parameters are kept constant (T_{on} = 20 µSec; T_{off} = 50 µSec; Ip = 15 ampere; Gap voltage = 32 volt; Tool down time =20 µSec; duty factor = 28.57 %.). The results are shown in table **4.8**

Table 4.5 Response characteristics with variation of current

Sl.No.	I_{Amp}	MRR (mg/min)	TWR(mg/min)	SR (Ra)(µm)
1	3	0.4	0.8	3.5
2	6	1.3	0.4	4.3
3	9	2.9	0.19	5.02
4	12	4.1	0.4	6
5	15	7.3	1.2	6.9
6	18	14.05	2.6	--

Table 4.6 Response characteristics with variation of Pulse on time

Sl. No.	T_{on}(µs)	MRR(mg/min)	TWR(mg/min)	SR(Ra)(µm)	Duty Cycle %
1	05	4.37	1.3	3.21	9.09
2	10	7.3	1.2	4.6	16.6
3	20	16.9	1.5	7.32	28.57
4	50	14	2.0	8.62	50.0
5	100	8.2	1.3	10.3	66.6
6	200	4.76	- 0.1	10.8	80.0
7	500	2.6	- 0.3	11.5	90.9
8	1000	1.6	- 0.4	9.76	95.23

Table 4.7 Response characteristics with variation of Pulse off time

Sl.No.	T_{off} (µs)	MRR (mg/min)	TWR(mg/min)	SR(Ra)(µm)	Duty Cycle %
1	5	4.98	0.3	5.3	80.0
2	10	6.5	0.5	5.13	66.6
3	20	6.3	0.6	7.5	50.0
4	50	12.1	1.03	9.62	28.57
5	100	5.9	0.8	4.3	16.66
6	200	4.57	0.5	4	10.0
7	500	2.4	0.2	3.5	3.84

Table 4.8 Response characteristics with variation of Pulse off time

Sl.No.	T_{lift}(µs)	MRR (mg/min)	TWR(mg/min)	SR(Ra)(µm)
1	5	27.05	0.8	10.4
2	10	15.36	0.6	8.2
3	20	11.6	0.5	6.03
4	50	10.7	0.4	4.92
5	100	5.2	0.3	5.1
6	200	3.6	0.3	4

1 Effect of Peak Current

The results have shown in table **4.5** and figures **4.5**, **4.6** and **4.7**. MRR increases with increase in peak current. TWR decreases with increase in current up to 9A then increases continuously. SR gradually increased up to 18A. at 18A the tool started melting and evaporation of tool material at the centre on the tool face and formed a cavity on the tool face so current range selected from 9A to 15A for the main experimentation.

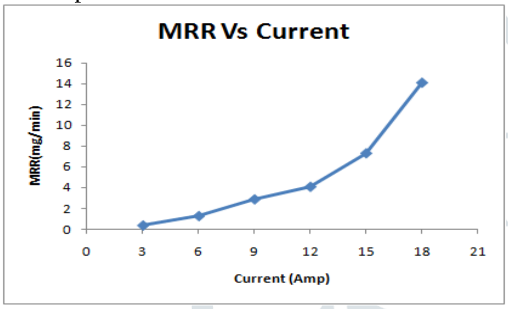


Fig. 4.5 Effect of current on MRR

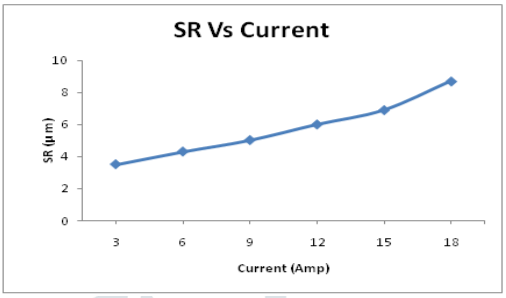


Fig. 4.6 Effect of current on Surface Roughness

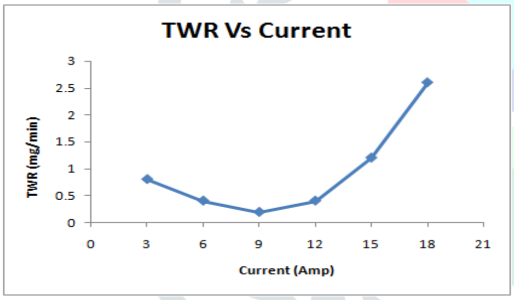


Fig. 4.7 Effect of current on TWR

Fig.4.4 Melting of tool at 18 Amps.

4.5.2 Effect of Pulse on Time

The results are depicted in figures **4.8, 4.9, 4.10.** MRR and TWR increases with increase in pulse on time up to 20 µSec then decreased continuously. At lower T_{on} sparking time is less and T_{off} is more, the time for flushing is more so the metal removal and SR are less. The SR increases continuously up to 500 µSec then decreases. It is observed that the MRR is higher at duty factor 28.57% and lower at 95.23%. The MRR and TWR are decreased from 20 µsec due to T_{on} increases T_{off} decreases so the time for flushing out the molten material is less so the molten material solidifies and forms as a layer on the machined surface that is the reason for the selection of pulse on time from 10µsec to 50 µsec.

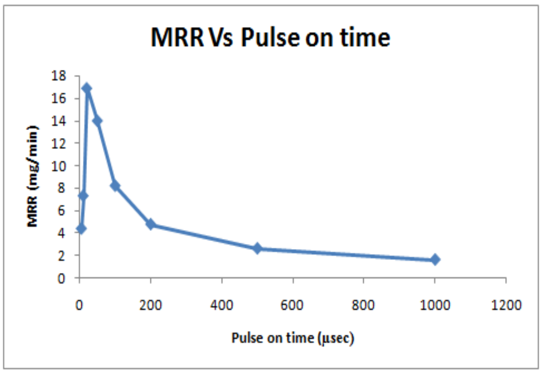


Fig. 4.8 Effect of Pulse on time on MRR

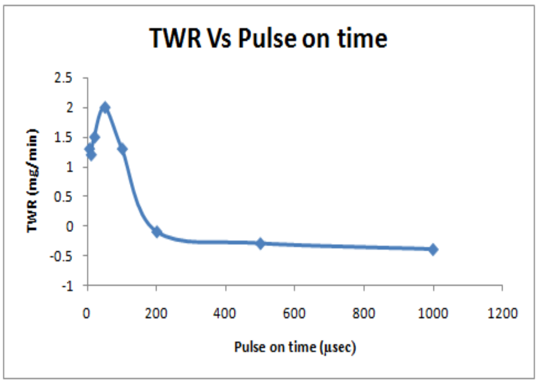
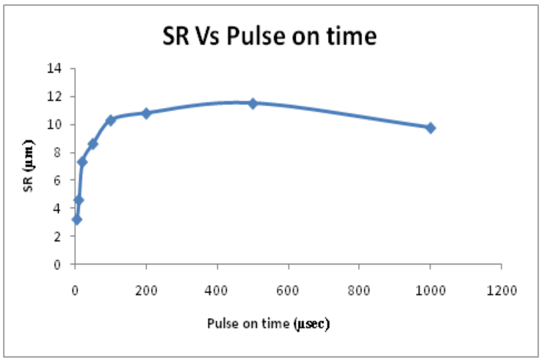


Fig. 4.9 Effect of Pulse on time on TWR



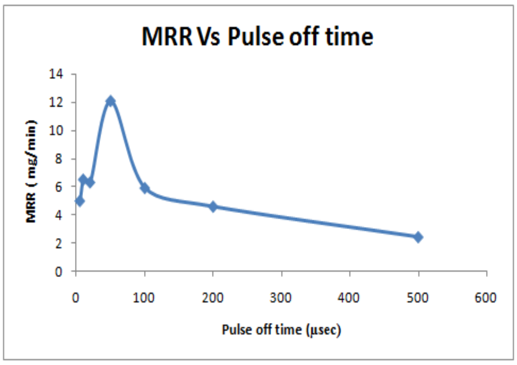
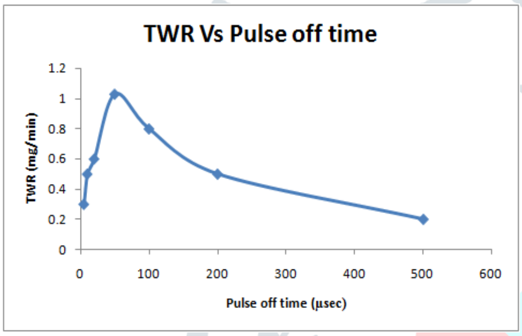


Fig. 4.10 Effect of Pulse on time on SR Fig. 4.11 Effect of pulse off time on MRR

4.5.3 Effect of Pulse off Time

Depicted in figure **4.11, 4.12** and **4.13** MRR, TWR and SR increases continuously with increase in T_{off} up to 50 µSec then decreases continuously due to sparking time for metal removal is less and duty factor decreases but flushing out the removed material was good so the SR decreased continuously. MRR is higher at 28.57% of duty factor. The range of T_{off} selected from 20 µsec to100µsec to obtain the higher MRR and better SR for main experimentation.



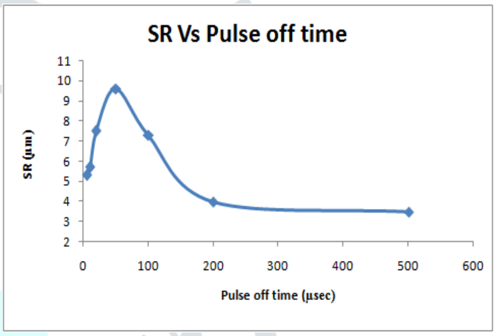
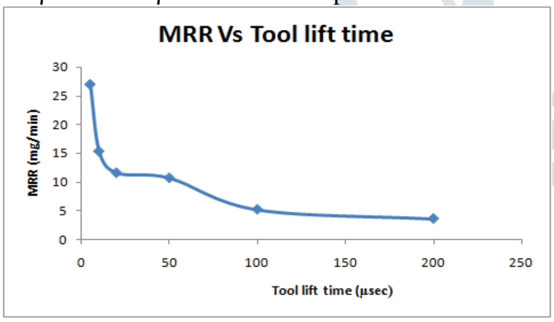


Fig. 4.12 Effect of pulse off time on TWR Fig. 4.13 Effect of pulse off time on SR

4.5.4 Effect of Tool lift time

Trends of curves for MRR, TWR and SR with Tool lift time are depicted in figures 4.14, **4.15** and **4.16** respectively. It is observed MRR, TWR and SR are decreases continuously because when the tool moves away from the work piece then increases the spark gap so the heat reached to the work surface is lesser so for higher MRR and better SR, the tool lift time range selected from 5 µsec to 20 µsec for main experimentation.



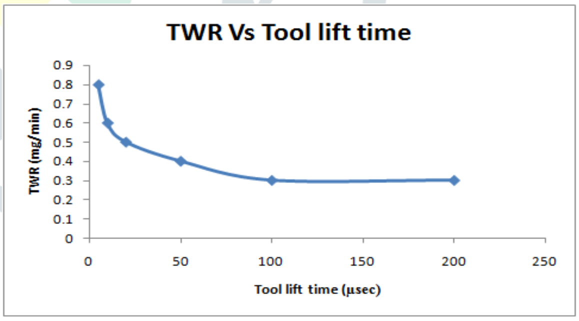


Fig. 4.14 Effect of tool lift time on MRR Fig. 4.15 Effect of tool lift time on TWR

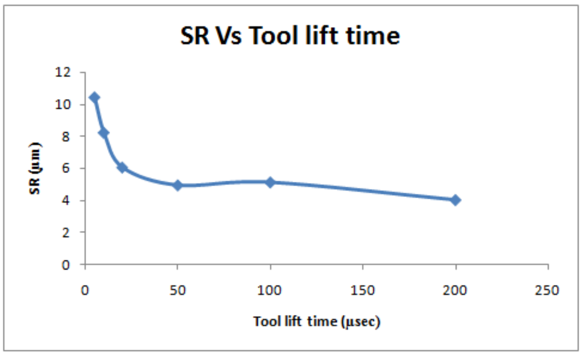


Fig. 4.16 Effect of tool lift time on Surface Roughness

Conclusions

1. The value of Metal removal rate is found to increase continuously with the increase in the value of current and at 18A tool started melting and evaporation and formed a cavity on the tool face.
2. The value of Metal removal rate is found to increase continuously with the increase in the value of pulse on time up to 20 micro seconds then it has decreased continuously.
3. Metal removal rate is found to increase continuously with increase in pulse off time up to 50 micro seconds then it has decreased continuously.
4. Metal removal rate is found to decrease continuously with increase in Tool lift time.
5. Electrode wear rate is found to decrease initially up to 9A current and later increased continuously with increase in the Current.
6. Electrode wear rate increased initially up 50 micro seconds and later decreased with increase in pulse on time and observed forming carbon in between tool and work piece it is found negative tool wear rate.
7. Electrode wear rate is found to increases with increase in pulse-off time up to 50 micro seconds then slowly decreased with increase in pulse-off time continuously beyond 50 micro seconds.
8. Tool wear rate is found to decrease continuously with increase in Tool lift time.
9. It is found that Surface roughness increased as the current increased and the effect of current on surface roughness is more as compared to the effect of pulse ON time and pulse OFF time.
10. It is found that as the Duty cycle increases MRR initially increases up to 28.57% then decreased. It is also found that as the Duty cycle increases TWR initially increases up to 50% then started decreasing
11. It is found that as the Duty cycle increases surface roughness decreases continuously.

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