

Performance Evaluation of Electrical Discharge Machining of Titanium Alloy

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The EDM process uses electric discharges or sparks to machine material. These discharges are set between the workpiece and the tool electrode. A dielectric fluid is used in which both of these components, viz. workpiece and the electrode, are such that these two do not make a physical contact with each other. A voltage is applied across the tool electrode and the workpiece used. This voltage is increased linearly upto a point where the intensity of the electric field around the tool electrode and the workpiece used. This voltage is increased linearly upto a point where the intensity of the electric field around the tool electrode submerged in the dielectric becomes greater than the dielectric strength of the dielectric used. Due to this, the voltage breaks the barrier and finally electric discharges are produced emerging from the tool electrode and impacting on the surface of the workpiece. In this way, the discharges strike the surface and remove the material by increasing the localized temperature. These discharges are not continuous, but rather repetitive. Mhatre et al. (2014), did their work on the grey relational parameters machining of titanium alloys by non-conventional method such as EDM, of alloys like Ti-6Al-4V. TWR, MRR, and surface roughness are some of the parameters that were optimized. Results revealed that the copper electrode that is used gives optimum performance in the terms of lower tool wear rate and high material removal rate, and surface roughness of the workpiece samples used. The experiment that was performed on the Ti-6Al-4V to study out the performance characteristics by using the Taguchi method which was based on the investigation of both the significant parameters on MRR was found to be the peak current and the pulse on time. The least effective factor was pulse-off time (T_{off}) and servo voltage. Aspinwall et al. (2008), has studied the microhardness of the Ti-6Al-4V alloy which is machined with the help of EDM process. He stated that the change of machined surface has not produced due to the repetition of passes. He also concluded that the high voltage causes the increase in the microhardness upto a certain depth. Chen et al. (2007), observed that the hardness was increased from a value of 200 HV to 750 HV. He attributed these

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results to the formation of oxide layers TiO_2 , TiNiO_3 and the debris that was found in the recast layers of the samples. Chen et al. (2008) investigated the machining characteristics of NiAlFe alloys using EDM process. The microstructure, composition, roughness and hardness of machined surfaces are discussed in this study. The $\text{Ti}_{35.5}\text{Ni}_{49.5}\text{Zr}_{15}$ high-temperature SMA is used as a comparative material. Sabouni et al. (2012) made research on EDM process parameter for NiTi SMA using graphite tool and they concluded that with increase in current MRR increases and when pulse on time increases MRR does not increase in this case as graphite is used as a tool material. MRR declines when pulse off time increases. Jatti and Singh (2014) studied the effects of cryogenic treatments on the machinability of NiTi shape memory alloys workpieces in electro discharge machining. Due to cryo-treatment the electrical conductivity of workpiece exceptionally improved. Experimental results showed about 19% increase in material removal rate of cryogenic treated workpieces. Variations in tool wear rate were found to be marginal. Walkar et al. (2014) investigated the effect of magnetic field on the material removal rate and surface roughness, in conjunction with the variation of electrical parameters like pulse on-off times and gap current, while keeping other electrical parameters and work piece/ tool material constant. An experimental result showed that the magnetic field assisted EDM improves the process stability. Sadasiva Rao et al. (2012) investigated the effect of process parameters such as speed, feed and depth of cut and approach angle of the cutter on cutting force, tool life and surface roughness in face milling of Inconel 718. The experiments were carried out based on L_9 orthogonal array under dry conditions. Grey relational analysis was implemented to optimize the multi performance characteristics to minimize the cutting force and surface roughness and maximize the tool life criteria. Refaie et al. (2010) used Taguchi method grey analysis to determine the optimal combination of control parameters in milling. The measures of machining performance were material removal rate and surface roughness. Gupta et al. (2013) studied the optimization of unidirectional glass fibre reinforced plastic composite by using Taguchi method and grey relational analysis. Mixed L_{18} orthogonal array is use during the study for conduction of experiments. Krishna et al. (2013) uses the Taguchi method for the friction stir welding of dissimilar metal for tensile properties. In order to improve product quality and weld optimized welding conditions are evaluated for maximum tensile strength. Singh et al. (2012) studied the effect of continuous and discontinuous vibration on work piece. In this study experiments were carried out using Taguchi's L_{18} orthogonal array. For experimentation high chromium high carbon steel is being used as work piece and copper is being used as tool material. On the basis of experiment they

concluded that discontinuous vibrations give more MRR and TWR. Also the intensity of development of cracks is more in case of discontinuous vibration as compared with continuous vibration. Sahoo et al. (2013) used response surface methodology and desirability approach to investigate cutting temperature during hard turning of EN24 steel. Optimization of processes parameter is obtained using desirability approach and prediction model was developed by response surface methodology. This observed value of hardness was found to be varying from the outermost surface of the machined sample to the innermost part of the sample.

This study aims at Evaluation of mechanical properties and surface parameters of titanium alloy samples after electric discharge machining.

Keywords- response, Evaluation, implemented, Experimental

Experimental Setup

ASKAR MICRONS V3525 die sinking electric discharge machine was used to carry out machining of the samples, as shown in figure 1. Servo mechanism controls the servo head gap voltage. It also controls the positive polarity, in the Z axis. Accuracy of 5 micrometer can be observed in all the three axes. Electric discharges emerged from the tool electrode and impacted on the workpiece, which led to material removal. As the material is removed, servo mechanism kicked in to maintain the gap between the workpiece and the tool electrode. It also controls the downward movement of the electrode. The dielectric medium used for flushing purpose is EDM 30 grade oil. During experiment side flushing is used to flush out removed material.

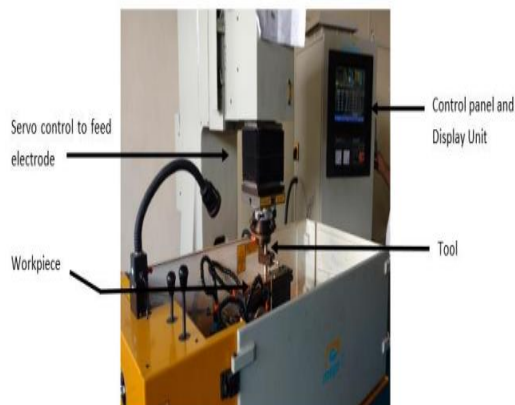


Fig. 1 Experimental Setup

Ti-6Al-4V workpiece of size: 100x25x5 mm³ and pure electrolytic copper (99.9%) as tool material was used in this study. Polarity considered in the study is tool as negative and workpiece as positive.

Table 1 Set-A Machining parameters

Current (A)	Pulse on time (μs)	Pulse off time (μs)	Voltage (V)
14	300	4	70
15	300	4	70
16	300	4	70
18	300	4	70
20	300	4	70
22	300	4	70
25	300	4	70

Table 2 Set-B Machining parameters

Current (A)	Pulse on time (μs)	Pulse off time (μs)	Voltage (V)
20	100	4	70
20	150	4	70
20	200	4	70

20	300	4	70
20	400	4	70
20	500	4	70
20	750	4	70

Table 3 Set-C Machining parameters

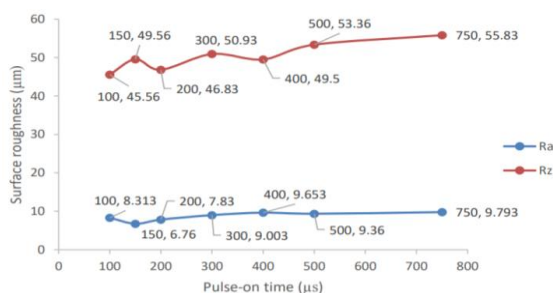
Current (A)	Pulse on time (μs)	Pulse off time (μs)	Voltage (V)
20	200	3	70
20	200	4	70
20	200	5	70
20	200	6	70
20	200	7	70
20	200	8	70
20	200	9	70

Results And Discussion

increases from 45.3 μm to 51.23 μm, for a gap current of 14 A to 25A.

It is observed that as the current is increased, surface roughness goes on increasing. This can be attributed to the fact that spark energy during machining is very high at the workpiece surface, which leads to the formation of wide and deep craters on the surface.

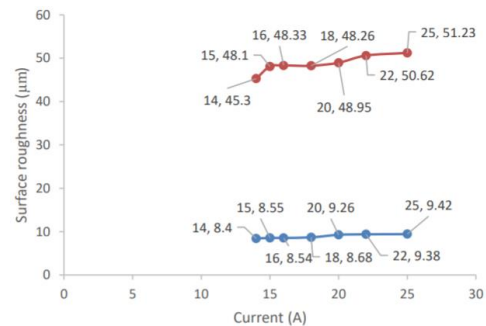
Effect of Pulse on time on Surface Roughness

**Fig.3 Effect of pulse on time on surface roughness**

During this, the parameters other than the pulse-on time such as pulse-off, current are kept

This section discusses the effect of input process parameters on performance measures considered in this study.

Effect of Gap Current on Surface Roughness

**Fig.2 Effect of current on surface roughness**

During this set of experiment, the current is varied and other parameters are kept constant such that $T_{on}=300 \mu s$, $T_{off} = 4 \mu s$, voltage = 70V. From the figure 2 it can conclude that the average surface roughness gradually increases from 8.4 μm to 9.42 μm, for a gap current of 14 A to 25A. From the graph it can conclude that the mean surface roughness gradually

constant. The values of the constant parameters are $T_{off} = 4 \mu s$, current = 20 A, voltage = 70 V.

The surface roughness shown in figure 3 is plotted against the pulse-on time. The average surface roughness decreases from 8.313 μm to 6.76 μm and then increases to 7.83 μm, between a pulse-on time of 100 μs to 200 μs. It further gradually increases up to 9.793 μm from 300 μs to 750 μs. The mean surface roughness (R_z) varies from 45.56 μm to 49.5 μm, for a pulse-on time off 100 μs to 400 μs. It then gradually increases upto 55.83 μm from 400 μs to 750 μs. As the pulse-on time is increased, the surface roughness of the workpiece goes on increasing. This can be attributed to the fact that as the pulse-on time is increased, spark energy available also increases. Therefore, this leads to a higher material removal rate, forming deeper discharge craters.

Effect of T_{off} on Surface Roughness

During this the parameters other than the pulse-off time are kept constant like $T_{on} = 200 \mu s$, Current = 20A, voltage = 70V. For average surface roughness, the rate of variation is negligible from $3 \mu s$ to $5 \mu s$ and then gradually increases to $8 \mu s$ and then decreases to $9 \mu s$, as seen from figure 4. The mean surface roughness gradually decreases from $3 \mu s$ to $6 \mu s$, after that it increases up to $8 \mu s$ and then decreases between surface roughness of 45 to $55 \mu m$. It is observed that as the pulse-off time is increased, the surface roughness decreases. Spark energy available for machining is inversely proportional to the pulse-off time. This means at higher pulse-off time, lesser spark energy is available at the workpiece surface which leads to low material removal rate, creating shallow craters on the surface of the workpiece.

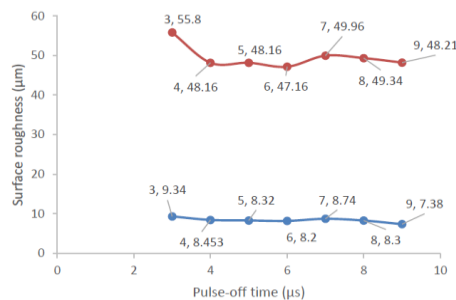


Fig.4 Effect of pulse off time on surface roughness

Effect of Gap Current on Ultimate Tensile Strength

The ultimate tensile strength decreases from $992 N/mm^2$ to $952 N/mm^2$ for the gap current ranging from $14 A$ to $17 A$, as seen from figure 5. It further shows decrease with minute variations from $952 N/mm^2$ to $944.88 N/mm^2$ ranging from $17 A$ to $25 A$.

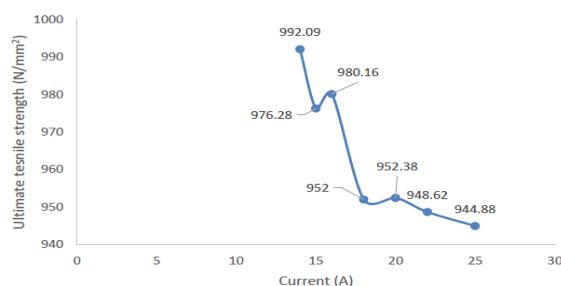


Fig.5 Effect of current on ultimate tensile strength

Effect of Pulse on time on ultimate tensile strength

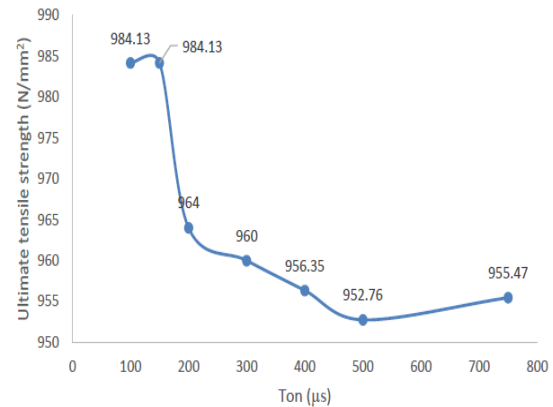


Fig.6 Effect of current on ultimate tensile strength

The ultimate tensile strength gradually decreases from $984.13 N/mm^2$ to $952.76 N/mm^2$ ranging from pulse on time $170 \mu s$ to $500 \mu s$ as depicted in figure 6.

Effect of Pulse off time on ultimate tensile strength

The UTS is found to be lowered from $1200 N/mm^2$ to an average of $963.77 N/mm^2$ for Set A (varying current), $965.97 N/mm^2$ for Set B (varying T_{on}), and $963.63 N/mm^2$ for Set C (varying T_{off}). A continuous decrease can be seen in the ultimate tensile strength from $980.16 N/mm^2$ to $968 N/mm^2$ for a pulse-off time of $3 \mu s$ to $4 \mu s$. A increase can be seen in the Ultimate Tensile Strength as the pulse-off time is increased from $4 \mu s$ to $6 \mu s$, can be seen from figure 7.

This can be attributed to the presence of brittle layers on the surface of the workpiece, which are formed during the EDM process and the equivalent tensile stresses that are generated in the workpiece. It has been found that the fatigue changes only slightly for different microstructural conditions of original material.

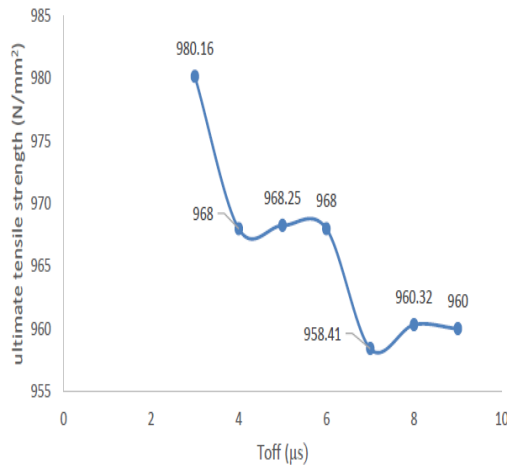


Fig.7 Effect of current on ultimate tensile strength

Effect of Current on Surface hardness

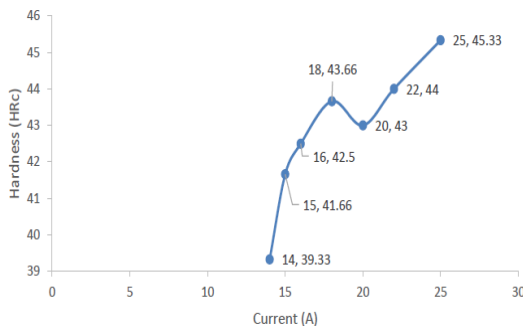


Fig. 8 Effect of current on surface hardness

Rockwell hardness was conducted on the unmachined surface of the samples. Three such readings were taken for these tests and the readings revealed that the hardness of the unmachined surface is 32 HRC. For a gap current from 14 A to 18 A, the surface hardness gradually increases from 39.33 HRC to 43.66 HRC, and then decreases to 43 HRC for a gap current of 18 A. Further surface hardness increases upto 45.33 HRC for gap current of 20 A to 25 A, can be seen from figure 8. The surface hardness of the material increases as the gap current is increased. This can be attributed to the fact that as the current increases, the operating temperature increases. At higher operating temperatures the sample gets heated too. The dielectric present assists in quenching of the

sample, which results in the increase in the surface hardness of the material.

Effect of Pulse on time on Surface hardness

For a Pulse-on time from 100 μs to 200 μs, the surface hardness gradually increases from 38 HRC to 41 HRC, and then remains constant upto a pulse-on time of 300 μs. This surface hardness further increases upto 45.33 HRC, for a pulse-on time of 300 μs to 750 μs, as depicted from figure 9. The surface hardness of the material increases as the pulse-on time is increased. This can be attributed to the fact that the pulse-on time increases, the operating temperature increases. At higher operating temperatures the sample gets heated too. The dielectric present assists in quenching of the sample, which results in the increase in the surface hardness of the material.

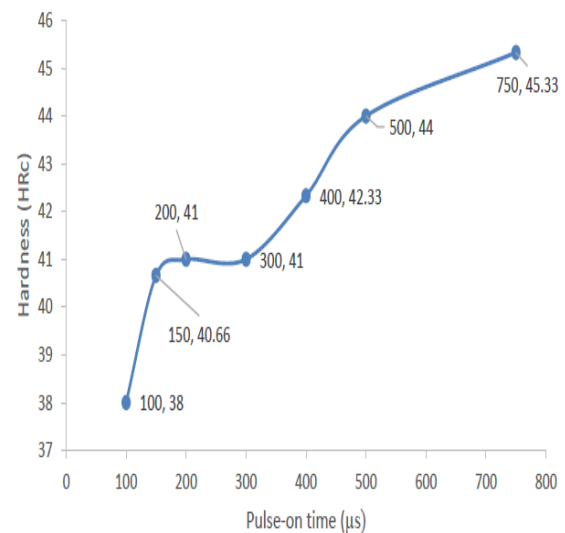


Fig. 9 Effect of pulse on time on surface hardness

Effect of Pulse off time on Surface hardness

For a Pulse-off time from 3 μs to 9 μs, the surface hardness gradually decreases from 33.33 HRC to 26.66 HRC. The surface hardness of the material decreases as the pulse-off time is increased. This can be attributed to the fact that as the pulse-off time increases, the operating temperature decreases as the spark energy available at the workpiece surface is less.

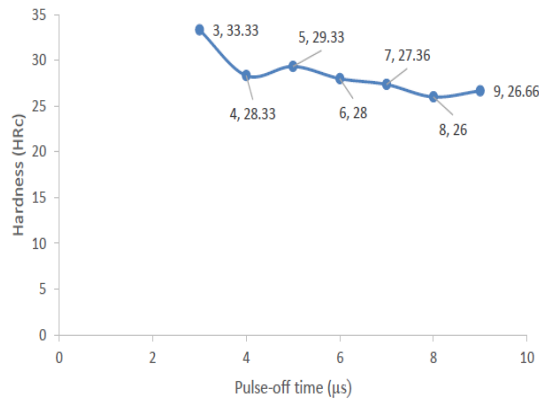


Fig. 10 Effect of pulse off time on surface hardness

CONCLUSION

Based on the data collected and analyzed by the different tests conducted on the machined samples by EDM process, the following observations were drawn:

- It was observed that as the current is increased, surface roughness goes on increasing. The maximum value of surface roughness obtained was $51.23\mu\text{m}$ at gap current of 25 A.
- As the pulse-on time is increased, the surface roughness of the workpiece goes on increasing. The maximum value of surface roughness obtained was $55.83\mu\text{m}$ at pulse on-time of 750 μs .
- It is observed that as the pulse-off time is increased, the surface roughness decreases. The maximum value of surface roughness obtained was $55.38\mu\text{m}$ at a pulse-off time of 3 μs .
- The Ultimate tensile strength decreases with increase in gap current. The maximum value of Ultimate tensile strength obtained was 992.09 N/mm², at a gap current of 15 A.

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• The Ultimate tensile strength decreases with increase in pulse-on time. The maximum value of Ultimate tensile strength obtained was 984.13 N/mm², at a pulse-on time of 100 μs .

• The Ultimate tensile strength decreases with increase in gap current. The maximum value of Ultimate tensile strength obtained was 980.16 N/mm², at a Pulse off time of 3 μs .

• Hardness was observed to increase with increase in gap current. The maximum value of hardness of 45.33 HRc, was obtained at a gap current of 25 A.

• Hardness was observed to increase with increase in pulse-on time. The maximum value of hardness of 45.33 HRc, was obtained at a pulse-on time of 750 μs .

• Hardness was observed to increase with increase in gap current. The maximum value of hardness of 33.33 HRc, was obtained at a pulse-off time of 3 μs .

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