ISSN XXXX XXXX © 2017 IJESC

Research Article Volume 7 Issue No.7

# Modelling and Optimization of WEDM Parameters for Titanium (Ti6al4v) using Response Surface Methodology

K.Tirupalu[1], Dr.G. Srinivasa Rao[2]
M.Tech Scholar[1], Professor[2]
Department of Mechanical Engineering
RVR & JC College of Engineering, Guntur, AP, India

**Abstract:**
The main goal of any manufacturing industry is to achieve improved process performance and higher productivity in order to survive in the present competitive scenario. Now-a-days many intricate or complex shapes of the products are developing with existing or newly developed materials. To achieve this, conventional machining operations have their own limitations in obtaining better surface finish and material removal rate while performing operations on the materials for complex shapes. The best choice of manufacturing conditions is one of the prime factors that has to be envisaged in the common manufacturing processes, especially, in those associated with Electrical Discharge Machining (EDM) and Wire Electrical Discharge Machining (WEDM). Such a process should be capable of machining geometrically complex or hard material components that are precise and difficult-to-machine such as heat-treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. That are being widely used in dies and mould-making industries, aerospace, aeronautics and nuclear industries. The limitations is a result of the failure to run the machine tools at their optimum operating condition. The problem of arriving at the optimum levels of the operating parameters has attracted the attention of the researchers and practicing engineers for a very long time. To avoid these limitations of conventional machining operations and to obtain better performance characteristics like surface finish, cutting speed, material removal rate etc. for hard and electrically conductive materials the unconventional machining process like Wire EDM is a mostly used.

**Keywords:** Titanium grade5 alloy, brass wire, chemical properties, machining properties

## I. INTRODUCTION

Accompanying the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. Nevertheless, such materials are difficult to be machined by traditional machining methods. Hence, non-traditional machining methods including electrochemical machining, ultrasonic machining, electrical discharging machine (EDM) etc. are applied to machine such difficult to machine materials. WEDM process with a thin wire as an electrode transforms electrical energy to thermal energy for cutting materials. With this process, alloy steel, conductive ceramics and aerospace materials can be machined irrespective to their hardness and toughness. Furthermore, WEDM is capable of producing a fine, precise, corrosion and wear resistant surface.

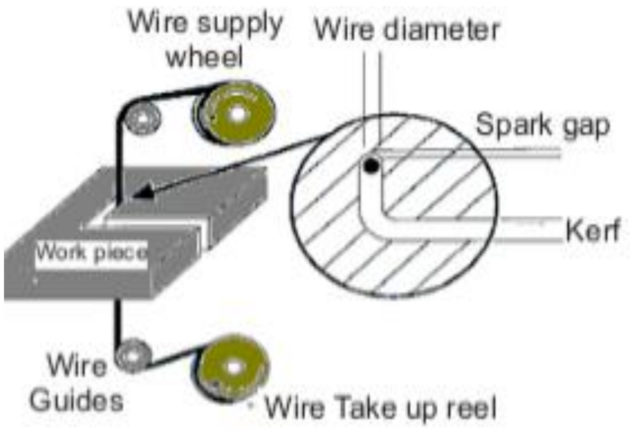


**Figure.1. Schematic Representation of Wedm**

S.B. Prajapati, N. S. Patel [1] evaluates the effect of pulse on-off time, voltage, wire feed and wire tension on MRR, SR, kerf and gap current in wire EDM. A series of experiments have been performed on AISI A2 tool steel in form of a square bar. Analysis of data optimization and performance is done by Response Surface Methodology (RSM). Dr. Josephkunju Paul et al [2] evaluates the effect of voltage, dielectric pressure, pulse on-time and pulse off-time on spark gap of Ti6AL4V alloy. It is found that the pulse on time, pulse off time, the interaction of dielectric pressure and pulse off time, and interaction of pulse on time and pulse off time are significant parameters which affect the spark gap of WEDM. Liao et al [3] studied the effect of specific discharge energy on WEDM characteristics of Ti- 6Al-4V and Inconel718. A quantitative relation between machining characteristics and machining parameters was derived. It was observed that two most significant factors affecting the discharge energy (η) are discharge-on time (pulse on time) and servo voltage. Moreover, discharge-on time and work piece height have a significant effect on machined groove width. Ashan et al [4] conducted experimental investigations to establish relationships for surface finish with current and voltage. They concluded that the machined surface becomes rougher with increase in current and voltage. Nishat [5] experimented on AISI 4140 steel to study the variation of cutting performance with cutting parameters in WEDM. The surface quality of the workpiece increased with decrease in pulse duration, open circuit voltage and wire speed, and with increasing dielectric fluid pressure. Tosun and Cogun [6] experimented to study the effect of cutting parameters on wire wear of AISI 4140 steel in WEDM process. It is found experimentally that the increasing pulse duration and open circuit voltage increase the WWR, however the increase in wire speed and dielectric fluid pressure decrease the WWR. Ranganath et al,Wire failure occurs in wire-EDM process as a result of severity in wire wear rate, which is a function of discharge current and discharge time. Kanlayasiri et al [7] used a Sodic A320 WEDM with wire electrode of 0.25mm diameter and DC53 was used as work piece material. He studied the effect of WEDM machining parameters pulse on time, pulse off time, pulse peak current, wire tension and surface roughness as response. The ANOVA technique was applied to find out the effect of process parameters on surface roughness. The ANOVA results were examined through residual analysis. Results from ANOVA showed that the surface roughness increased with the increase of pulse on time and pulse peak current. Basil et al [8] conducted a series of experiments to evaluate the machine performance of grade-5 titanium alloy in WEDM. Design of experiments was adopted in this study to determine the optimum condition of machining parameters and the significance of each parameter on the performance of machining characteristics.

## II. MATERIALS & EXPERIMENTAL DETAILS

Titanium is a metal with excellent corrosion resistance, fatigue resistance, a high strength-to weight ratio that is maintained at elevated temperature. Titanium is a very strong and light metal. This property causes that titanium has highest strength-to-weight ratio in comparison the other metal that are studied to medical use. Machining titanium and its alloys by conventional machining methods has some difficulties such as high cutting temperature and high tool wear ratio. Thus, titanium and its alloys are classified as difficult-to-machine materials.

Therefore, unconventional machining process is introduced for machining titanium and its alloys. Ti-6Al-4V is most widely used titanium grade, further classified as wrought titanium. It is a two phase $\alpha + \beta$ titanium alloy with aluminum as the alpha stabilizer and vanadium as beta stabilizer and this has been selected as work material for this present study. Ti-6Al-4V has a resistivity on the order of five times larger than steel which is used in various applications such as aircraft gas turbine disks and blades, rings, airframe structural components, fasteners, vessels, cases, hubs, biomedical implants, prosthetic devices, engine components, offshore, power generation industries etc.

**Table.1. Chemical Composition of Material**

| C | Fe | N | O2 | Al | V | H | Ti |
|---|---|---|---|---|---|---|---|
| <0.08 % | <0.25 % | <0.05 % | <0.2 % | 5.5-6.76 % | 3.5-4.5% | 0-0.15 % | Balance |

## III EXPERIMENTAL WORK

The work piece is TITANIUM GRADE5 with dimensions 300mm × 20mm × 5mm. Brass wire with 0.25mm diameter is used as electrode. Dielectric solution is distilled water and dielectric pressure is 3Kg/min.

**Table.2. Physical Properties of Material**

| MATERIAL | THERMAL CONDUCTIVITY (W/m-k) | MELTING POINT (ºC) | THERMAL DIFFUSIVITY ($m^2/s$) | DENSITY ($g/cm^2$) | ROCKWELL C HARDNESS |
|---|---|---|---|---|---|
| Titanium Grade5 | 6.8 W/m-k | 1650º C | 2.8$m^2/s$ | 4.4g/c$m^2$ | 33 |

## EXPERIMENTAL DESIGN

Central Composite Design (CCD) is used to conduct experiments for 5 factors at three levels. The standard CCD plan requires 27 experiments to be conducted, each involving different combinations of process variables. In this 27 experiments, 16 experiments are from factorial design, 8 experiments from center point. Following table shows process parameters and their levels, considered for the experimentation.

**Table.3. Machining parameters and their levels**

| | PULSEON TIME (Ton) | PULSE OFF TIME (Toff) | PEAK CURRENT (IP) | SERVO VOLTAGE (SV) | WIRE FEED (WF) |
|---|---|---|---|---|---|
| UNITS | µsec | µsec | Ampere | Voltage | m/min |
| LEVEL 1 | 100 | 51 | 10 | 10 | 5 |
| LEVEL 2 | 107 | 57 | 11 | 11 | 6 |
| LEVEL 3 | 114 | 63 | 12 | 12 | 7 |

## IV. RESULTS AND DISCUSSIONS

The plan of tests is developed aiming at determining the relation between process parameters and performance parameters like cutting speed, material removal rate, surface roughness. The analysis of experiments was made into two phases. The first one is concerned with the analysis of effects of factors and interactions. Model for surface roughness is developed in the second phase.

### ANALYSIS OF THE FACTORS AND INTERACTIONS

**CUTTING SPEED:** From the factorial portion of CCF design, both factor and interaction effects (at two levels) can be obtained. It can be observed from axial and central portion of CCF design, considering experiments from 17 to 26, factor effects (at three levels) of each factor can be obtained when all other factors are at 0 levels. Using the experimental data level means is calculated. The level means obtained from factorial portion of CCF design, axial portion of CCF design for cutting speed are given. The influence of each control factor can be more clearly presented in response graph. A response graph shows the change in response when the settings of control factors are changed from one level to other. The slope of the line determines the power of influence of a control factor.

**Table.4. Response values**

| SL NO | Machine Time (min) | Wire Diameter (mm) | Cutting Speed (mm/min) | MRR (mm³/min) | Kerf Width (mm) | Surface Roughness (µm) |
|---|---|---|---|---|---|---|
| 1 | 66.50 | 0.25 | 0.25 | 25 | 0.30 | 7.32 |
| 2 | 65.30 | 0.25 | 0.28 | 28 | 0.30 | 5.32 |
| 3 | 67.80 | 0.25 | 0.25 | 25 | 0.30 | 3.20 |
| 4 | 58.90 | 0.25 | 0.37 | 37 | 0.30 | 6.94 |
| 5 | 85.00 | 0.25 | 0.17 | 17 | 0.25 | 4.77 |
| 6 | 75.00 | 0.25 | 0.26 | 26 | 0.30 | 7.57 |
| 7 | 75.00 | 0.25 | 0.28 | 28 | 0.25 | 6.40 |
| 8 | 69.00 | 0.25 | 0.31 | 31 | 0.25 | 4.42 |
| 9 | 7.23 | 0.25 | 1.99 | 199 | 0.25 | 6.19 |
| 10 | 8.15 | 0.25 | 1.97 | 197 | 0.25 | 7.70 |
| 11 | 7.35 | 0.25 | 2.27 | 227 | 0.25 | 7.28 |
| 12 | 7.18 | 0.25 | 2.35 | 235 | 0.30 | 8.07 |
| 13 | 12.23 | 0.25 | 1.58 | 158 | 0.30 | 5.26 |
| 14 | 19.53 | 0.25 | 1.03 | 103 | 0.30 | 4.70 |
| 15 | 10.10 | 0.25 | 2.03 | 203 | 0.30 | 4.24 |
| 16 | 14.23 | 0.25 | 1.29 | 129 | 0.30 | 5.72 |
| 17 | 40.43 | 0.25 | 0.47 | 47 | 0.25 | 5.33 |
| 18 | 7.53 | 0.25 | 2.47 | 247 | 0.25 | 4.57 |
| 19 | 11.25 | 0.25 | 1.67 | 167 | 0.30 | 7.30 |
| 20 | 33.20 | 0.25 | 0.61 | 61 | 0.25 | 6.91 |
| 21 | 24.00 | 0.25 | 0.65 | 65 | 0.25 | 4.09 |
| 22 | 19.28 | 0.25 | 1.03 | 103 | 0.25 | 6.23 |
| 23 | 17.30 | 0.25 | 1.27 | 127 | 0.25 | 5.46 |
| 24 | 22.22 | 0.25 | 0.88 | 88 | 0.25 | 7.00 |
| 25 | 19.26 | 0.25 | 1.05 | 105 | 0.25 | 5.00 |
| 26 | 19.19 | 0.25 | 1.00 | 100 | 0.25 | 9.63 |
| 27 | 19.56 | 0.25 | 0.96 | 96 | 0.25 | 6.13 |

**ANALYSIS AND DISCUSSION OF CUTTING SPEED**

**Table.5.Average response of cutting speed for factorial portion of CCF design**

| | Ton | Toff | IP | SV | WF |
|---|---|---|---|---|---|
| LEVEL -1 | 0.27 | 1.22 | 0.94 | 1.10 | 1.05 |
| LEVEL 1 | 1.81 | 0.87 | 1.14 | 0.98 | 0.99 |
| DIFFERENCE | 1.54 | 0.35 | 0.2 | 0.12 | 0.06 |
| RANK | 1 | 2 | 3 | 4 | 5 |

Cutting speed is mostly affected by Ton followed by Toff, IP, SV and WF. The affect of SV and WF on cutting speed is negligible due to less difference between their two levels. The same is represented by means of response graphs which are shown below.

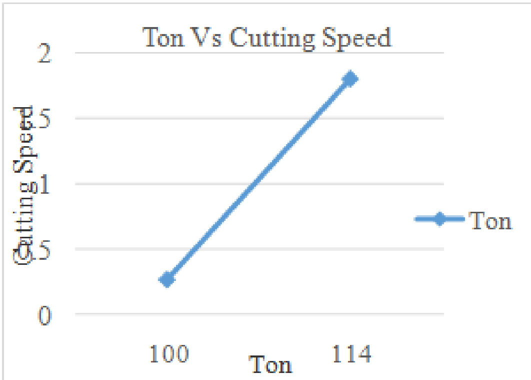


**Figure.2. RESPONSE GRAPH – Ton Vs Cutting Speed**

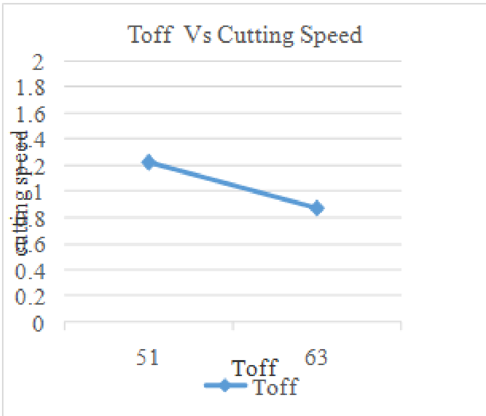


**Figure.3. RESPONSE GRAPH – Toff Vs Cutting Speed**

**ANALYSIS AND DISCUSSION OF MRR:**

**Table .6. Average response of MRR for factorial portion of CCF design**

| | Ton | Toff | IP | SV | WF |
|---|---|---|---|---|---|
| LEVEL -1 | 27.125 | 121.625 | 94.125 | 110.25 | 105.25 |
| LEVEL 1 | 181.375 | 86.875 | 114.375 | 98.25 | 103.375 |
| DIFFERENCE | 154.25 | 34.75 | 20.25 | 12 | 1.87 |
| RANK | 1 | 2 | 3 | 4 | 5 |

MRR is mostly affected by Ton followed by Toff, IP, SV and WF. The affect of WF on MRR is negligible due to less difference between their two levels. The same is represented by means of response graphs which are shown below.

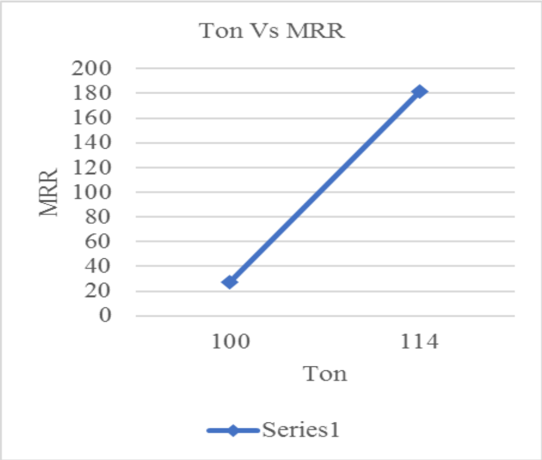


**Figure.4. Response graph – ton vs mrr**

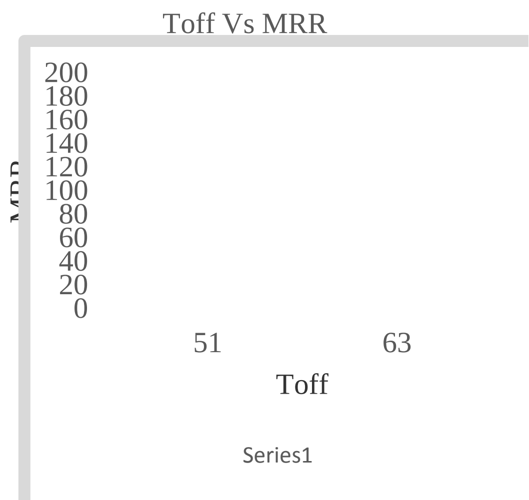


**Figure.5. Response graph – toff vs mrr**

**TABLE.7. Average response of Machining time for one factor at a time analysis**

| | Ton | Toff | IP | SV | WF |
|---|---|---|---|---|---|
| LEVEL -1 | 40.43 | 11.25 | 24 | 17.30 | 19.26 |
| LEVEL0 | 20.58 | 20.97 | 21.104 | 21.52 | 21.65 |
| LEVEL 1 | 7.53 | 24.00 | 19.28 | 22.22 | 19.19 |
| DIFFERENCE | 32.9 | 12.75 | 4.72 | 4.92 | 0.07 |
| RANK | 1 | 2 | 4 | 3 | 5 |

Ton and Toff are most significant factors affecting on Machining time followed by SV, IP. The Parameter WF is having less impact on Machining time. The same is represented by means of response graphs which are shown below.

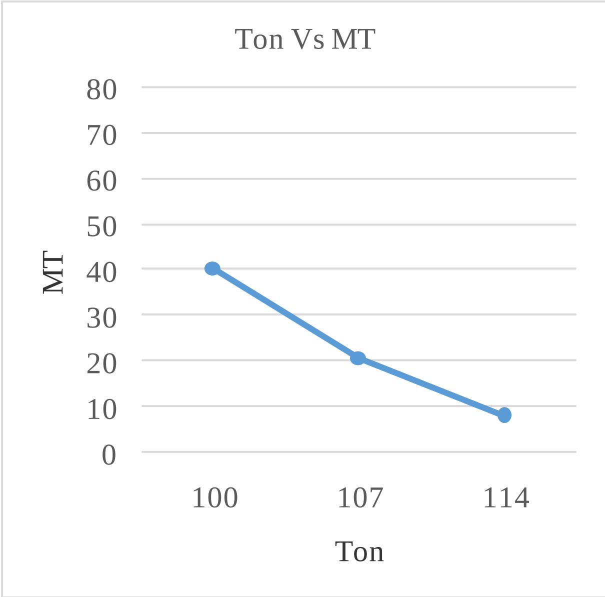


**Figure.6. RESPONSE GRAPH – Ton Vs MRR**

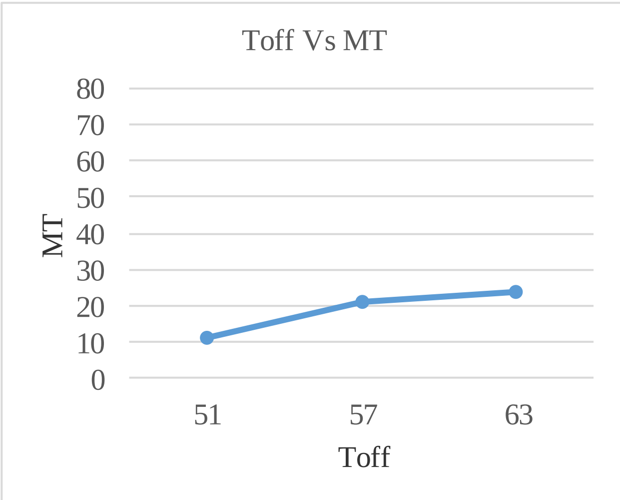


**Figure.7. RESPONSE GRAPH – Toff Vs MRR**

## V. CONCLUSIONS

In this work, five output parameters cutting speed, machining time, material removal rate, kerf and surface roughness are investigated by varying five process (machining) parameters on Ti-6Al-4V with brass wire as electrode in electric discharge machine. The process parameters included pulse on time (Ton), pulse off time (Toff), peak current (IP), Wire feed (WF), servo voltage (SV). Experiments were conducted according to central composite face centered design (CCF). Using the experimental data, response tables and response graphs are plotted for one factor at a time analysis and factorial portion of CCF design. Based on the work the following conclusions may be drawn.

1. Cutting speed is mostly affected by Ton followed by Toff, IP, SV and WF. The affect of SV and WF on cutting speed is negligible due to less difference between their two levels.
2. Ton and Toff are most significant factors affecting on Cutting speed followed by IP and SV. The Parameter WF is having less impact on cutting speed.

3. MRR is mostly affected by Ton followed by Toff, IP, SV and WF. The affect of WF on MRR is negligible due to less difference between their two levels.
4. Toff and Ton are most significant factors affecting on MRR followed by SV and IP. The Parameter WF is having less impact on MRR.
5. Kerf is mostly affected by SV followed by IP, Ton, Toff and WF. The affect of Ton, Toff and WF on Kerf is negligible due to less difference between their two levels.
6. Toff and Ton are most significant factors affecting on Kerf followed IP and WF.The Parameter SV is having less impact on Kerf.
7. Surface Roughness is mostly affected by WF followed by Toff, Ton, SV and IP. The affect of SV and IP on Surface Roughness is negligible due to less difference between their two levels.
8. WF and IP are most significant factors affecting on Surface Roughness followed by SV and Ton . The Parameter Toff is having less impact on Surface Roughness.
9. Machining time is mostly affected by Ton followed by Toff, IP, SV and WF. The affect of SV and WF on Machining time is negligible due to less difference between their two levels.
10. Ton and Toff are most significant factors affecting on Machining time followed by SV, IP . The Parameter WF is having less impact on Machining time.

## VI. REFERENCES


[1].Abdulkareem, S., Ali Khan, A., Zain, Z. M. (2011) ‘‘Experi - mental Investigation of Machining Parameters on Surface Roughness in Dry and Wet Wire-Electrical Discharge Machining’’ Advanced Materials Research Vols. 264-265 pp. 831-836.

[2].Anand, K. N., (1996): ‘‘Development of process technology in wire-cut operation for improving machining quality’’, to- tal Quality Management, Vol.7:1, pp. 11-28.

[3].Antar, M.T. ,Soo S.L., Aspinwall, D.K., Jones, D., Perez, R.(2011) ‘‘Productivity and workpiece surface integrity when WEDM aerospace alloys using coated wires’’ Proce- dia Engineering Vol.19, pp.3 – 8

[4].Datta, S., Mahapatra S. S., (2010). ‘‘Modeling, simulation and parametric optimization of Wire- EDM process using response surface methodology coupled with grey-Taguchi technique’’ International Journal of Engineering Science and Technology. Vol.2, pp. 162-183.

[5].Dauw, D.F., Albert, L., (1992). ‘‘About the evolution of wire tool performance in wire EDM’’. Annals CIRP. Vol.41 (1), pp. 221-225.

[6].Hassan, M. A., Mehat, N. S., Sharif, S., Daud, R., Tomadi, S. H. , Reza, M. S.(2009) ‘‘Study of the Surface Integrity of AISI 4140 Steel in Wire Electrical Discharge Machining’’ Proceedings of the International Multi Conference of Engineers and Computer Scientists Vol. II, pp.1-6.

[7].Hewidy, M.S., El-Taweel T.A., El-Safty M.F.(2005) ‘’Mod- elling the machining parameters of wire electrical discharge machining of Inconel 601 using RSM’’ , Journal of Materials Processing Technology. Vol. 169, pp. :328–336.

[8].Ho, K.H., Newman, S.T. , Rahimifard, S. , Allen, R.D., (2004) ‘‘State of the art in wire electrical discharge machin- ing (WEDM)’’International Journal of Machine Tools & Manufacture Vol.44,pp.1247–1259.

[9].Ghodsiyeh,D.a, Golshan,A. Hosseininezhad,N., Hashemzadeh, M., and Ghodsiyeh,S., (2012) ‘‘ Optimiz- ing Finishing process in WEDMing of Titanium Alloy (Ti6Al4V) by Zinc Coated Brass Wire based on Response Surface Methodology’’ Indian Journal of Science and Technology,Vol.5, Issue 10,pp.:3365-3377.

[10].Ghodsiyeh D.b, Lahiji MA, Ghanbari M, Shirdar MR and Golshan A (2012) ‘‘Optimizing Material Removal Rate (MRR) in WEDMing Titanium alloy (Ti6Al4V) using the Taguchi method’’. Research Journal of Applied Sciences, Engineering and Technology, Vol. 4(17), pp.3154- 3161.

[11].13.Ghodsiyeh D., Davoudinejad, A., Hashemzadeh, M., Hosseininezhad, N., and Golshan A (2013) ‘‘Optimizing Finishing Process in WEDMing of Titanium Alloy (Ti6Al4V) by Brass Wire based on Response Surface Methodology’’ Re- search Journal of Applied Sciences, Engineering and Tech nology

[12].Choi, K.K., Nam, W.J., Lee Y.S. (2008) ‘‘Effects of heat treatment on the surface of a die steel STD11 machined by W-EDM’’ journal of materials processing technology, Vol. 201,pp. 580–584.

[13].Han, F., Zhang, J., Soichiro, I. (2007) ‘‘Corner error simula- tion of rough cutting in wire EDM’’ Precision Engineering Vol. 31, pp. 331– 336

[14].Han,F., Jiang, J., Yu, D., (2007a) ‘‘Influence of machining parameters on surface roughness in finishcut of WEDM’’The International Journal ofAdvanced Manufacturing Technol- ogy. Vol. 34, Issue 5-6, pp 538-546.

[15].Han,F., Jiang, J., Yu, D., (2007b) ‘‘Influence of discharge current on machined surfaces by thermo-analysis in finish cut of WEDM’’ International Journal of Machine Tools and Manufacture Vol. 47, Issues 7–8, pp.1187–1196.

[16].Hewidy, M.S., El-Taweel T.A., El-Safty M.F.(2005) ‘’Mod- elling the machining parameters of wire electrical discharge machining of Inconel 601 using RSM’’ , Journal of Materials Processing Technology. Vol. 169, pp. :328–336.Ho, K.H., Newman, S.T. , Rahimifard, S. , Allen, R.D., (2004) ‘‘State of the art in wire electrical discharge machin- ing (WEDM)’’ International Journal of Machine Tools &Manufacture Vol.44,pp.1247–1259

[17].Hsue,W.J., Liao, Y.S. , Lu, S.S. (1999)‘‘Fundamental ge- ometry analysis of wire electrical discharge machining in corner cutting’’. International Journal of Machine Tools & Manufacture Vol.39 , pp.651–667

[18].Huang, J.T., Liao, Y.S. and Hsue, W.J., (1999). ‘‘Determi- nation of finish-cutting operation number and machining parameters setting in wire electrical discharge machining’’. Journal of Materials Processing Technology, Vol. 87, pp.69– 81