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PARAMETRIC OPTIMIZATION OF WIRE CUT - EDM OF TITAMIUM ALLOY (TI6AL4V) BY USING VARIANCE OF ELECTRODES

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ABSTRACT

Wire cut electrical discharge machining (WEDM) is a modification of electrical discharge machining (EDM) which has been widely used for machining of materials when precision is important. The optimization of process parameters in WEDM to obtain highest degree of dimensional accuracy and surface finish is one of the most challenging tasks. A zinc coated wire and brass wire of 0.25mm diameter were used as tool electrode. This work has been established as a comparison of the two wires in terms of surface roughness and MRR on Titanium alloy (Ti-6Al-4V) and experimentally studied. The purpose of this study is to investigate the effect of parameters like Pulse ON time, Pulse OFF time, Dielectric pressure and Peak current on Surface roughness (Ra) and Material Removal Rate (MRR). Analysis of Variance was employed to determine level of significance of the machining parameters and mathematical model is developed by means of linear regression analysis.

Keywords: Titanium alloy (Ti 6Al 4V), Surface roughness (Ra) and Material removal rate (MRR).

1. Introduction

WEDM is one of the non-traditional processes which is accepted globally to machine high strength to weight ratio materials mainly employed for nuclear and aerospace industries. This (WEDM) is one of the main applications of the traditional electrical discharge machine (EDM). EDM machining was first discovered by the English scientist Joseph Priestly in 1770, but its advantage were utilized completely only in the year 1943 by Russian scientists and it was commercially developed in the year 1970. In the mid of 1980s this technique was used in machine tools to machine electrically conducting materials. The basic principle of WEDM process is shown in the figure 1. WEDM uses a continuously travelling wire electrode which is made of thin copper, brass or tungsten or coated wire of standard diameter of 0.25mm. A dielectric fluid is forced into the machining area to improve the effectiveness as well as to flush the eroded particles from the machining gap. Most commonly used dielectric fluid in WEDM is deionized water.

The outstanding characteristics of titanium alloys such as their compatibility and noticeable physical, mechanical and biological performances has led to increased application of them in various industries especially in biomedical industries over the last 50 years. However, due to low thermal conductivity of titanium and its alloys and their reactivity with cobalt in most tool materials and the high localised mechanical stress together with thermal stressed induced from rubbing the chips on the chip–tool contact area lead to crater wear on the tool rake face close to the cutting edge. The presence of the crater wear has the potential to weaken the cutting edge and result in catastrophic tool failure; these are the difficulties in machining titanium and its alloys by conventional machining. On the other hand, unconventional machining processes especially Wire Electrical Discharge Machining (WEDM) are more appropriate techniques for machining difficult to machine materials like titanium and its alloys. Hence WEDM is chosen to cut titanium alloy (Ti-6Al-4V).

This study aims to examine the influence and to evaluate the effects of machining parameters on performance characteristics, and to identify the optimal performance characteristics under the best settings of machining parameters like 'pulse on time', 'pulse off time', 'peak current' and 'dielectric fluid pressure', on surface roughness and material removal rate in WEDM on titanium alloy (Ti6Al4V) by using variance tool electrodes.

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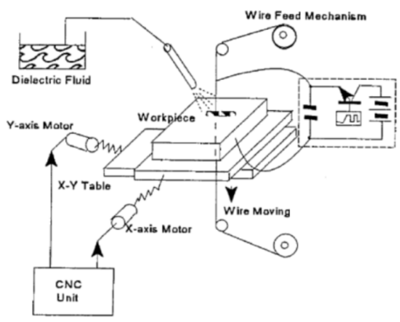


Fig. 1 Basic principle of WEDM process [15]

2. Literature Review

There are many number of works was published that reveal the influence of WEDM process parameters on the surface roughness and material removal rate of different materials. Mohinder P.Garg, Ajai Jain and Gian Bhushan [1] have investigated the effect of process parameters on material removal rate (MRR) and overcut using Box-Behnken designs and found the effect of pulse on time and pulse off time on dimensional deviation. It was observed that dimensional deviation increased when pulse on time increased and pulse off time decreased due to impingement of increased spark discharge energy on work piece. The investigations made by J.T. Huan and Y.S.Liao had analyzed the setting of optimal machining parameters like pulse on time, pulse off time, wire feed, voltage, dielectric pressure to obtain maximum metal removal rate, gap width and minimum surface roughness [2]. Pardeep Gupta et.al studied the effect of process parameters on kerf width and analysis of results indicates that the spark gap voltage, pulse on time, peak current and pulse off time have a significant effect on kerf width and saw that kerf width decreases with increase in pulse on time [3]. S.S. Mahapatra and Amar Patnaik have studied the Optimization of wire electrical discharge machining (WEDM) process parameters using genetic algorithm. The analysis shows that interactions between discharge current and pulse duration, interaction between pulse duration and pulse frequency play significant role in finish cutting operations [4].

S.Sivakiran et.al had made an attempt to study the influence of various machining parameters and relationship between control parameters and Output parameter (MRR) is developed by means of linear regression. Orthogonal Array (OA) designs have been used on EN-31 tool steel to achieve maximum metal removal rate using zinc coated copper wire electrode. The order strength of parameters are found from response table is current, pulse on, Bed speed and pulse off [5]. Pujari Srinivasa Rao et.al observed the effect of WEDM conditions on surface roughness using Taguchi Method. Amongst various process parameters they found that the peak current and pulse on time have most significant effect on Surface Roughness of Al BIS 24345. Surface Roughness decreased with decrease in peak current and pulse on time. It was also clear that wire tension and spark gap voltage are significant parameters in obtaining better surface finish [6].

D.Sathishkumar, M.Kanthababu et.al has performed investigation of WEDM characteristics of Al6063/SiCp Composites. It is also found that the influence of gap voltage (V) is more significant than that of other parameters for MRR. Voltage (V), pulse-on time (TON), wire feed (F) and pulse-off time (TOFF) are found to be the order of influence as the percentage of SiC increases in the MMCs for achieving higher MRR [7]. An attempt is made by S. Sarkar , S. Mitra and B. Bhattacharyya to Parametric optimization of wire electrical discharge machining of γ titanium aluminide alloy through an artificial feed – forward neural network type 6-15-3 was used to construct the WEDM process model. To get good dimensional control the wire offset value along with surface finish and cutting speed was considered as measure of process performance. A program was developed that will make one to select the optimum parametric combination that will result in maximum productivity at same time maintaining the required surface finish within limits [8].

Vamsi Krishna Pasam et.al has optimized surface finish in WEDM of Ti6Al4V using taguchi's parameter design method. They considered eight control parameters Ignition pulse current, short pulse duration, Time between two pulses, Servo speed, Servo reference voltage, Injection pressure, Wire speed and Wire tension and studied their behavior on surface finish. Genetic Algorithm was generated which is useful in optimizing surface roughness [9]. Dr.Joseph kunju Paul et.al has performed modeling of WEDM using Ti alloy Grade 5. They found that pulse on time, dielectric pressure, the interaction of voltage and pulse on time are significant parameters which affect the surface roughness and improper setting of pulse on time and pulse off time can leads to wire breakage [10]. Danial Ghodsiyeh et.al have performed the optimizing Material Removal Rate (MRR) in WEDMing Titanium alloy (Ti 6Al 4V) as a work piece and experimental was based on the Central Composite Design (CCD) and Face cantered. MRR and Surface roughness are influenced by Pulse on time and Peak current and these factors have an opposite relationship [11, 12].

Selvakumar et.al has performed a concurrent optimization of the responses namely cutting speed, surface roughness and corner inaccuracy during machining of aluminium 5083 alloy and they found that the geometrical accuracy of the product was improved by predicting dimensional shift and passing the same to the CNC programme as wire off set (wire compensation) value [13].

3. Experimental Setup

The experimental set up adopted for this study is given in figure 2. The experiments were carried out on a wire-cut EDM machine (ELEKTRA SPRINTCUT 734) of Electronica Machine Tools Ltd. A Falcon (Zinc coated) and HH brass wire (Nickunj edm wires) of 0.25mm is used as the tool electrode. 'Pulse on time', Pulse off time', Dielectric pressure' and 'Peak current' are the four process parameters that were selected for investigations.

Fig. 2 ELECTRONICA SPRINTCUT 734 Machine

All other machine parameters were kept constant during the time of machining. The chemical composition of the material given by the Energy-dispersive X-ray spectroscopy (EDAX Test) in percentage of weight are as follows, Al= 5.97, Ti= 90.25 and V=3.78. The composition confirms that the material tested on EDAX is Titanium alloy grade 5 (Ti-6Al-4V). The size of the work piece considered for experimentation on the wire-cut EDM is 200 mm x 55 mm x 5 mm and specimens of 10mm x 10mm x 5mm size are cut. Tables 1 shows Material properties of Titanium alloy (Ti-6Al-4V). In this work the surface roughness was measured by Computer controlled Surface Roughness Tester (Surfcorder SE3500), KOSAKA LABORATORY LTD.

4. DESIGN OF EXPERIMENTS

The experiment designs were done based on the Taguchi Method. Genichi Taguchi a Japanese scientist developed a technique based on Orthogonal Array of experiments. This technique has been widely used in different fields of engineering to optimize the process parameters. A full factorial design with all factors at three levels provides the estimation of all the required parameter combinations. The control factors considered for the study are Pulse ON time, Pulse OFF time, Dielectric pressure and Peak Current. Three levels for each control factor will be used. Based on number of control factors and their levels, L9 (34) orthogonal array (OA) was selected. Table 2 represents various Optimizing parameter levels.

Table: 1 Material Properties of Titanium alloy (Ti-6Al-4V) [14]

Property	Metric
Density	4.42 g/cm^3
Melting point	1650°C
Co-Efficient of Expansion	9.0 µm/m.°C (21-93°C)
Poisson's Ratio	0.33
Modulus of elasticity	105-120 kN/mm^2
Tensile Strength, Ultimate	1170 N/mm^2
Tensile Strength, Yield	1100 N/mm^2

5. Results and Analysis

5.1 Results for brass wire electrode

The various machining parameters in three levels and corresponding results of Material removal rate (MRR) and Surface roughness (Ra) are tabulated in table 3.

After putting the data from Table 3 to the MINITAB 15 software the following figures and tables have been obtained.

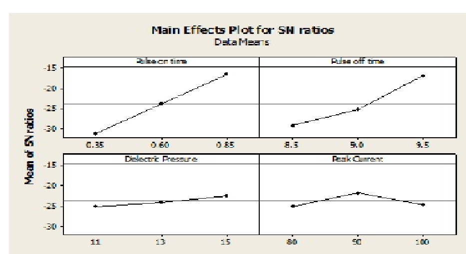
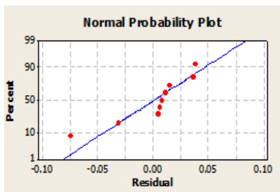


Fig. 3 Main Effects Plots for SN Ratios (MRR)

The figure 3 shows main effects plot – S/N Ratio for Material removal rate (MRR) with process parameters. It is evident from the figure 3 that the increase of pulse on time and peak current will increases discharge energy. This increases the depth and diameter of discharge crater, raising MRR, but spoiling the surface finish. Also decrease of pulse off time will increase the MRR. Hence lowering the peak current and pulse on time is preferable to get better surface finish. It is noted that increase in dielectric pressure will increases the Material removal rate.



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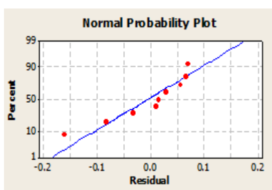
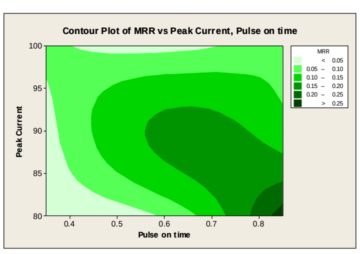


(b)

Fig. 4 Normal Plot of Residual (a) MRR (b) Ra

In figure 4, the normal probability plots of residuals for quadratic models are shown. According to the normal probability plots, the distribution of the residual along the normal % probability line is normal which indicates the error distribution for all groups of data is almost normal.



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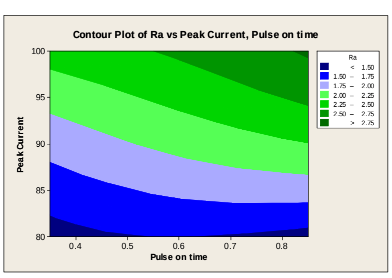


Fig. 5 Contour Plots for (a) MRR (b) Ra

Table 2: Levels of Various Optimizing Parameters

PARAMETER	SYMBOL	UNITS	LEVEL 1	LEVEL 2	LEVEL 3
Pulse on- time	A (µs)	Machine unit	105	110	115
Pulse off-time	B (µs)	Machine unit	26	28	30
Dielectric pressure	C	kgf/cm^2	11	13	15
Peak current	D	Amp	80	90	100

FIXED PARAMETERS	VALUES
Wire Feed or Speed	5 m/min
Wire tension	900gram
Machining Voltage	80V
Servo Voltage	30V
Servo Feed Setting	1115 for constant feed
Wire Material	Zinc coated & HH Brass
Tool Polarity	Negative

The figure 5 shows the contour plot for (a) Material removal rate, (b) Surface roughness connecting pulse on time and peak current. The pulse on time and pulse off time should be always carefully select otherwise, the results is frequent wire breakage.

The regression equation for Material removal rate (MRR)

MRR = - 1.08 + 0.302 Pulse on time + 0.137 Pulse off time + 0.00317 Dielectric Pressure - 0.00321 Peak Current

The regression equation for Surface roughness (Ra)

Ra = - 2.28 + 0.585 Pulse on time - 0.0958 Pulse off time - 0.0148 Dielectric Pressure + 0.0556 Peak Current

5.2 Results for Zinc coated wire electrode

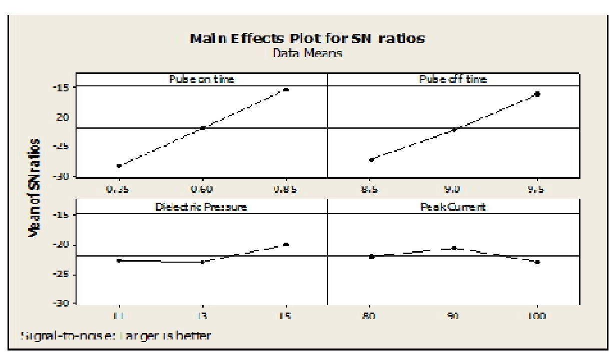
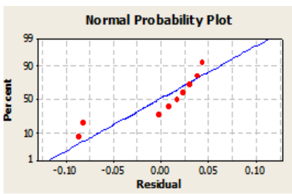


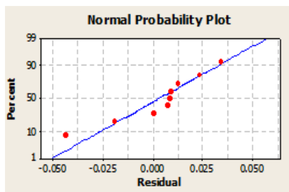
Fig. 6: Main Effects Plots for SN Ratios (MRR)

The figure 6 shows main effects plot – S/N Ratio for Material removal rate (MRR) with process parameters.

The effects of all parameters are same as brass wire electrode but better results are obtained.



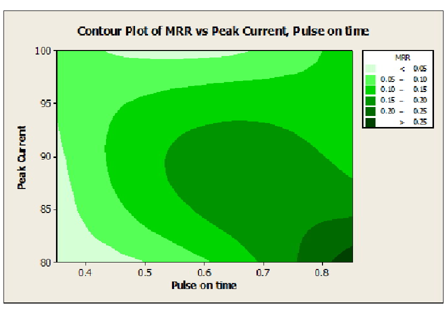
(a)



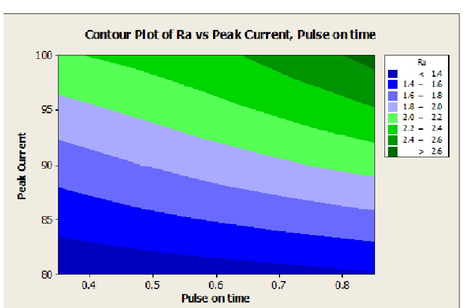
(b)

Fig. 7 Normal Plot of Residual (a) MRR (b) Ra

In figure 7, the normal probability plots of residuals for quadratic models are shown. According to the normal probability plots, the distribution of the residual along the normal % probability line is normal which indicates the error distribution for all groups of data is almost normal and error obtained by using zinc coated wire is less than brass wire.



(a)



(b)

Fig. 8 Contour Plots for (a) MRR (b) Ra

The figure 8 shows the contour plot for (a) Material removal rate, (b) Surface roughness connecting pulse on time and peak current. The pulse on time and pulse off time should be always carefully select otherwise, the results is frequent wire breakage. But by using zinc coated wire as electrode, the wire breakage can be minimized.

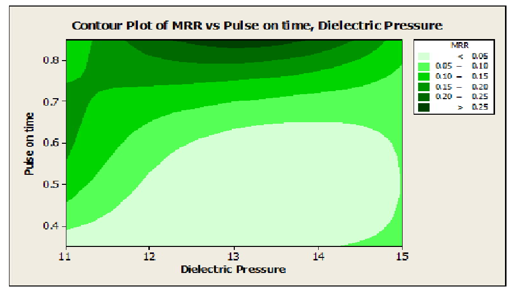


Fig. 9 Contour Plots for MRR for both wires

The figure 9 shows the contour plot for Material removal rate connecting pulse on time and dielectric pressure. It is observed that the material removal rate is the most when dielectric pressure is in the range of 12.5 to 14 kgf/cm^2 approximately. During rough cutting operation, cutting performances have been improved since the removed particles in the machining gap are evacuated more efficiently.

The regression equation for Material removal rate (MRR)
MRR= - 1.07 + 0.304 Pulse on time + 0.134 Pulse off time + 0.00220 Dielectric Pressure - 0.00274 Peak Current

The regression equation for Surface roughness (Ra)
Ra = - 2.64 + 0.701 Pulse on time - 0.0592 Pulse off time - 0.0222 Dielectric Pressure + 0.0545 Peak Current

5.3 Discussion

5.3.1 Material removal rate (MRR)

In the present study material removal rate is a measure of job cutting which is calculated by using below formulae (Volumetric Material Removal Rate) and is given quantitatively in mm^3/sec.

$$\textbf{MRR} = \frac{Wa - Wb}{Tm \times \rho} \; (\mathrm{mm^3/sec}) \qquad \textbf{[5, 7, 11, \& 12]}$$

where, Wb and Wa are weights of work piece material before and after machining (gram), respectively. Tm is machining time (sec) and ρ is the density of Ti-6Al-4V (0.00442g/mm^3). The result indicates, this factor reveals that Pulse on time significantly affects MRR on using both electrodes. Increasing the pulse on time will affects the time of each discharge and raises the material removal rate. This factor is the highest contribution. Moreover, peak current and pulse off time is the other main factors influenced in MRR.

Table 3: Experimental design and Results

EXP NO:	Pulse on time (µs)	Pulse off time (µs)	Dielectric Pressure (kgf/cm^2)	Peak Current (Amp)	HH Brass Wire Electrode: Material Removal Rate (mm^3/sec)	HH Brass Wire Electrode: Surface Roughness (µm)	Zinc Coated Wire Electrode: Material Removal Rate (mm^3/sec)	Zinc Coated Wire Electrode: Surface Roughness (µm)
1	105	26	11	80	0.011127	1.40	0.018405	1.25
2	105	28	13	90	0.029041	1.84	0.037424	1.69
3	105	30	15	100	0.066508	2.36	0.080546	2.18
4	110	26	13	100	0.030621	2.54	0.033279	2.36
5	110	28	15	80	0.056266	1.50	0.092826	1.30
6	110	30	11	90	0.159673	2.07	0.167814	1.89
7	115	26	15	90	0.121343	2.24	0.130521	2.07
8	115	28	11	100	0.099027	2.78	0.129867	2.67
9	115	30	13	80	0.277505	1.41	0.283430	1.38

5.3.2 Surface roughness (Ra)

By analysis it reveals that peak current is main factor that influenced on Surface roughness and which is the highest contribution. Again it is worth to repeat that the energy of every discharge is affected by peak current. The higher each discharging make the deeper and bigger crater is created by the released energy, resulting in influence on the surface roughness. By increasing pulse on time, localized sparking will be more possible to happen. Poor surface finish will be the outcome of localized sparking. Less peak current and more pulse off time is more desirable for achieving a better surface finish. This is same for both wire electrodes but surface roughness obtained by using zinc coated wire is less when compared to the HH brass wire.

5.3.3 Comparative performance of Brass and Zinc coated wires

The optimal sets of process parameters were obtained for various performance measures using Taguchi's design of experiment methodology. The summary results of predicted optimal values of the responses are given in the table 4 and figure 10 and 11 shows the surface roughness graph obtained from Computer controlled surface roughness tester.

Table 4: Optimal values of the responses

Wire Material	Performance Measures/ Responses	Optimal Set Of Parameters	Predicted Optimal Value
Brass Wire	Material Removal Rate	A_3 B_3 C_2 D_1	0.277505m m^3/sec
	Surface Roughness	A_1 B_1 C_1 D_1	1.40 µm
Zinc Coated Wire	Material Removal Rate	A_3 B_3 C_2 D_1	0.283430m m^3/sec
	Surface Roughness	A_1 B_1 C_1 D_1	1.25 µm

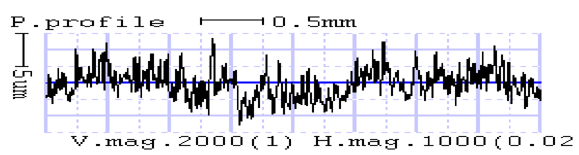


Fig. 10 Graphs obtained for Surface roughness (Ra=1.4µm)

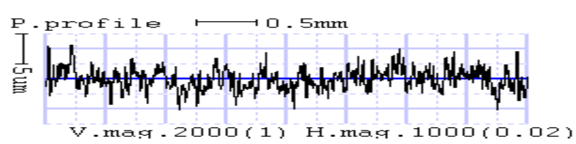


Fig. 11 Graphs obtained for Surface roughness (Ra=1.25µm)

5.3.3.1 Comparison of Output

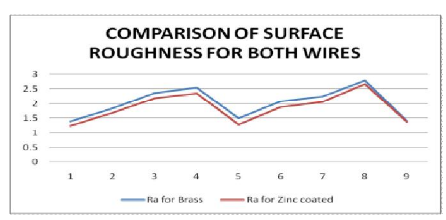


Fig. 12 Comparison of Ra for Both Wires

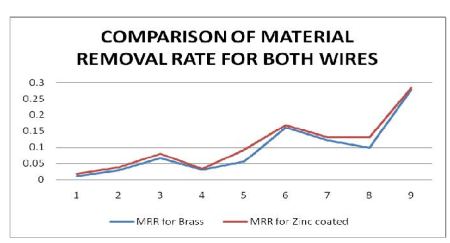


Fig. 13 Comparison of MRR for Both Wires

From the above figure 12 & 13, it is evident that performance of Zinc coated wire appears to be better and more economical in obtaining higher material removal rate and less surface roughness.

6. Conclusion and Future Enhancement

6.1 Conclusion

1. Ranges of process parameters have been established based on review of literature and by performing the pilot experiments using one factor at a time (OFAT) approach.

2. The effects of the process parameters on response characteristics viz. Material Removal Rate and Surface roughness were studied.

   (a) The Pulse on time and Pulse off time have significant effect on Material removal rate in machining of titanium alloy with both wire types.

   (b) As pulse on time and peak current increase, the cutting speed and MRR increases but surface roughness increases. This is due to the increase in discharge energy and enhancement in pulse on time and peak current.

   (c) Also, increase in wire tension and pulse off time causes reduction in surface roughness.

3. Zinc-coated brass wire results in higher cutting speed and smoother surface finish compared with high-speed brass wire. It has good electrical conductivity that helps the wire transfer energy to work piece efficiently. Thus, it leads to low heat energy in the part's surface and decreases the size of damaged layer.

6.2 Future Enhancement

The combination of various process parameters such as Pulse on time, Pulse off time, Peak current, Dielectric pressure, Servo reference voltage, Wire speed and Wire tension can be optimized and their values can be changed to higher range or lower range and further optimization can be studied by using Titanium Alloy Grade 5 and Grade 19.

References

1. *Mohinder Garg P, Ajai Jain and Gian Bhushan (2012), "An Investigation into Dimensional Deviation Induced by Wire Electric Discharge Machining of High temperature Titanium alloy", Journal of Engineering and Technology, Vol. 2 (2), 104-112*

2. *Huang J T and Liao Y S (2001), "Application of Grey Relational Analysis to Machining Parameters Determination of Wire Electrical Discharge Machining", The Thirteen International Symposium For Electromachining, Spain, 9-11 May 2001, 447-462*

3. *Pardeep Gupta, Rajesh Khanna, Rahul Dev Gupta and Neeraj Sharma (2012), "Effect of Process Parameters on Kerf Width in WEDM for HSLA Using Response Surface Methodology", Journal of Engineering and Technology, Vol. 2(1), 01 – 06*

4. *Mahapatra S S and Amar Patnaik (2006), "Optimization of wire electrical discharge machining (WEDM) process parameters using genetic algorithm", Indian Journal of Engineering & Materials Sciences, Vol. 13, 494-502*

5. *Sivakiran S, Bhaskar Reddy C and Eswara reddy C (2012), "Effect of Process Parameters on MRR in Wire Electrical Discharge Machining of En31 Steel", International Journal of Engineering Research and Applications, Vol. 2(6), 1221-1226*

6. *Pujari Srinivasa Rao, Koona Ramji and Beela Satyanarayana (2011), "Effect of WEDM Conditions on Surface Roughness: A Parametric Optimizations Using Taguchi Method", International Journal of Advanced Engineering Sciences and Technologies, Vol. 6(1), 041 – 048*

7. *Satishkumar D, Kanthababu M, Vajjiravelu V, Anburaj R, Thirumalai Sundarrajan N and Arul H (2011), "Investigation of wire electrical discharge machining characteristics of Al6063/SiCp composites", Int J Adv Manuf Technol,Vol. 56, 975–986*

8. *Sarkar S, Mitra S, Bhattacharyya B (2006), "Parametric optimization of wire electrical discharge machining of γ titanium aluminide alloy through an artificial neural network model", Int J Adv Manuf Technol, Vol. 27, 501–508*

9. *Vamsi Krishna Pasam, Surendra Babu Battula, Madar Valli P and Swapna M (2010), "Optimizing surface finish in WEDM using the taguchi parameter design method", J. Braz. Soc. Mech. Sci. & Eng. vol.32, 107-113*

10. *Basil Kuriachen, Josephkunju Paul, Jose Mathew (2012), "Modeling of Wire Electrical Discharge Machining Parameters Using Titanium Alloy (Ti-6AL-4V)", International Journal of Emerging Technology and Advanced Engineering, Vol.2, 2250-2459*

11. *Danial Ghodsiyeh, Mohammadreza Askaripour Lahiji and Mahdi Ghanbari (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), 3154-3161*

12. *Danial Ghodsiyeh (2013), "Review on Current Research Trends in Wire Electrical Discharge Machining (WEDM)", Indian Journal of Science and Technology, Vol. 6(2), 0974-6846*

13. *Selvakumar G, Sarkar S, Mitra S (2013), "An experimental analysis of single pass cutting of aluminium 5083 alloy in different corner angles through WEDM", Int. J. of Machining and Machinability of Materials, Vol.13, 262 – 275*

14. *Titanium Alloy Guide, www.RMITitanium.com*

15. *Thesis referred www.nitkkr.ac.in/files/.../Ph.D*

