International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2015): 6.391

Investigations in to Wire Electro Discharge Machining of Ti Alloys VT20 (BT20)

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Abstract: ***Wire electric discharge machine (WEDM) is a spark erosion non-conventional machining method to cut hard and conductive material with the help of a wire electrode. Ti Alloy V20 (BT20) is a hard alloy with high hardness and wear resisting property. The purpose of this study is to investigate the effect of parameters on surface roughness & cutting rate for WEDM using Ti Alloy V20 (BT20) as work-piece and brass wire as electrode. Ti Alloys VT20 (BT20) are metals which contain a mixture of titanium and other chemical elements. Such alloys have very high tensile strength and toughness (even at extreme temperatures). They are light in weight, have extraordinary corrosion resistance and the ability to withstand extreme temperatures. These are used in military applications, aircraft, spacecraft, cars, trucks, cranes, bridges medical devices, consumer electronics, roller coasters and other structures that are designed to handle large amounts of stress. It is observed that cutting rate and surface roughness increases with increase in pulse on time and peak current. Cutting rate and surface roughness decreases with increase in pulse off time and servo voltage. Wire mechanical tension has no significant effect on cutting rate and surface roughness. Response Surface methodology (RSM) is used to optimize the process parameter for cutting rate and surface roughness. Response Surface Methodology is formulating a mathematical model which correlates the independent process parameters with the desired cutting rate and surface roughness. The central composite design (CCD) has been used to conduct the experiments.***

Keywords: Keywords: Cutting rate; response surface methodology; surface roughness; WEDM.

1. Introduction

1.1 Introduction of WEDM

Electrical discharge machining (EDM), sometimes colloquially also referred to as spark machining, spark eroding, burning, die sinking, wire burning or wire erosion, is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks)[1]. Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the "tool" or "electrode", while the other is called the work piece-electrode, or "work piece". The process depends upon the tool and work piece not making actual contact. When the voltage between the two electrodes is increased, the intensity of the electric field in the volume between the electrodes becomes greater than the strength of the dielectric (at least in some point(s), which breaks, allowing current to flow between the two electrodes. This phenomenon is the same as the breakdown of a capacitor (condenser) (see also breakdown voltage). As a result, material is removed from both electrodes. Once the current stops (or is stopped, depending on the type of generator), new liquid dielectric is usually conveyed into the inter-electrode volume, enabling the solid particles (debris) to be carried away and the insulating properties of the dielectric to be restored.

Adding new liquid dielectric in the inter-electrode volume is commonly referred to as "flushing". Also, after a current flow, the difference of potential between the electrodes is restored to what it was before the breakdown, so that a new liquid dielectric breakdown can occur.

2. Literature Review

Ho et al. [1] Provides a review on the various academic research areas involving the WEDM process, and is the sister paper to a review by Ho and Newman on die-sinking EDM. It first presents the process overview based on the widely accepted principle of thermal conduction and highlights some of its applications. The main section of the paper focuses on the major WEDM research activities, which include the WEDM process optimization together with the WEDM process monitoring and control.

The final part of the paper discusses these topics and suggests the future WEDM research direction. They have organized the various WEDM research into two major areas namely WEDM process optimization together with WEDM process monitoring and control [1].

Sarkar et al. [2] Presents an investigation on wire electrical discharge machining of titanium aluminide alloy. An extensive research study has been carried out with an aim to select the optimum cutting condition with an appropriate wire offset setting in order to get the desired surface finish and dimensional accuracy.

The process has been modeled using additive model in order to predict the response parameters i.e. cutting speed, surface finish and dimensional deviation as function of different control parameters and the main influencing factors are determined for each given machining criteria. Finally, the optimum parametric setting for different machining situation arising out of customer requirement shave been synthesized and reported in the paper

Liao et al. [3] suggested that a suitable selection of machining parameters for the wire electrical discharge machining (WEDS) process relies heavily on the operators technologies and experience because of their numerous and diverse range. Machining-parameters tables provided by the machine-tool builder cannot meet the operators' requirements. Since for an arbitrary desired roughness of the machining surface, they do not provide the optimal machining conditions. An approach to determine parameters setting is proposed. Based on the Taguchi quality design method and the analysis of variance the significant factors affecting the machining performance such as metal removal rate, gap width, surface roughness, sparking frequency, average gap voltage and normal ratio (ratio of normal sparks to total sparks) are determined.

Kuriakose et al. [4] Titanium alloys are increasingly used in aerospace and automotive industries, and also used as medical implant material in wide variety of applications. Wire-electro discharge machining (WEDM) is an important non-traditional machining process, widely used for machining a variety of difficult-to-machine materials including titanium alloys with intricate shapes. The process is essentially a thermal process and the nature of surface produced is studied in this paper. It is observed that more uniform surface characteristics are obtained with coated wire electrode. Among the parameters such as time between two pulses, pulse duration, injection pressure, wire speed and wire tensions that have more influence on the surface characteristics, the time between two pulses is the most sensitive parameter [4].

Patil and Brahmankar [5] proposed a semi-empirical model for material removal rate in WEDM based on thermo-physical properties of the work piece and machining parameters such as pulse on time and average gap voltage. The model was developed by using dimensional analysis and non-linear estimation technique such as quasi-Newton and simplex. Predictability of this model was proposed more than 99% for all work materials they had studied. The work materials were silicon carbide particulate reinforced aluminum matrix composites.

The experiments and model prediction show significant role of coefficient of thermal expansion in WEDM of these materials. In addition, an empirical model, based on response surface method, was also been developed & the comparison of these models was carried out.

Soo et al. [6] carried out the experimental data for the fatigue behavior of aero engine alloy Ti-6Al-2Sn-4Zr-6Mo following wire electrical discharge machining (WEDM), with minimum damage generator technology and optimized trim pass strategies. Comparative results for flank milled samples were also given together with associated micrographs detailing work piece subsurface integrity and fracture initiation.

Despite a marginally higher S-N response for the milled specimens was compared to the wire machined samples when subject to a finishing regime, linear regression statistical analysis suggested no significant difference in performance at the 5% level based on slope responses. Micrographs showing sample crack initiation sites and fatigue crack growth paths suggest a 40-50μm altered zone in fracture surfaces for milled specimens with fatigue striations defining the crack path. For WEDM surfaces, crack initiation was in some cases due to defects below the machined surface, with secondary cracks probably due to local stresses.

Nourbakhsh et al. [7] carried out the experimental investigation of wire electro-discharge machining (WEDM) of titanium alloy. The objective was to investigate the effect of seven process parameters including pulse width, servo reference voltage, pulse current, and wire tension on process performance parameters (such as cutting speed, wire rupture and surface integrity). A Taguchi L18 design of experiment (DOE) was applied. All experiments were conducted using Charmilles WEDM. It was also found that the cutting speed increases with peak current and pulse interval. Surface roughness was found to increase with pulse width and decrease with pulse interval. The Analysis of Variance (ANOVA) also indicated that voltage, injection pressure, wire feed rate and wire tension have non-significant effect on the cutting speed. Scanning Electron Microscopic (SEM) examination of machined surfaces was performed to understand the effect of different wires on work piece material surface characteristics. A brief review of WEDM of titanium alloy was also included.

Sharma et al. [8] studied Multi Quality Characteristics of WEDM Process Parameters with RSM. The purpose of their study was to investigate the effect of parameters on metal removal rate for WEDM using High strength low alloy steel (HSLA) as work-piece & brass wire as electrode.

HSLA used in cars, trucks, cranes, bridges, roller coasters and other structures that are designed to handle large amounts of stress. It was observed that metal removal rate and surface roughness increases with increase in pulse on time and peak current. Metal removal rate and surface roughness decreases with increase in pulse off time and servo voltage. Wire mechanical tension has no significant effect on metal removal rate and surface roughness. Response Surface methodology (RSM) was used to optimize the process parameter for metal removal rate and surface roughness. Response Surface Methodology is formulating a mathematical model which correlates the independent process parameters with the desired metal removal rate and surface roughness. The central composite rotatable design (CCRD) has been used to conduct the experiments.

The mathematical model so developed was analyzed and optimized the process parameters producing optimal values of response variables. In their study influence of process parameters on metal removal rate and surface roughness was investigated. The parameters and their combinations affecting the process were obtained using ANOVA. Total 32 experiments were conducted and average values of MRR (mm3/min) and SR (μm). For analysis of data, checking the lack of fit of model was required. The model adequacy checking includes test for significance of regression model and lack of fit test. For this purpose Analysis of Variance (ANOVA) was performed.

3. Experimental Details

3.1 Response Surface Methodology and Design of Experimentation

Response surface methodology (RSM) is a collection of mathematical and statistical techniques those are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response. There is a loss of productivity due to the wire breakage. A thorough pilot study is to be carried out for the selection of process parameters range and their combination, so that loss of productivity can be minimized. Polynomial response surface in RSM has great advantages, it has a few disadvantages also. One such disadvantage is that the polynomials are untrustworthy when extrapolated beyond the experimental region. Another important disadvantage of using second order polynomial in RSM is that the size of experiments becomes too large and analysis becomes too complicated with more than three *X* variables or with more than three levels. However, a well-designed experimental plan can substantially reduce the total number of experiments. Central composite designs (CCD) are one of those means. Preceding a step ahead, central composite

designs of second order have been found to be the most efficient tool in RSM to establish the mathematical relation of the response surface using the smallest possible number of experiments without losing its accuracy.

3.2 Work Material

Titanium Alloy VT20 (BT20) of classification as Titanium wrought alloy is used as work material. The details of these materials are provided in Table 1

Table 1: Chemical Composition of Ti Alloy V20 (BT20)

Fe	C	Si	Mo	V	N	Ti	Al	Zr	O	H	Impurity
max 0.25	max 0.1	max 0.15	0.5 - 2	0.8 - 2.5	max 0.05	85.15 - 91.4	5.5 - 7	1.5 - 2.5	max 0.15	max 0.015	other 0.3

3.3 WEDM Equipment

The experiments are conducted by using Charmilles Robofil 300 Series Wire Electrical Discharge Machine (WEDM) manufactured by Charmilles Technology, Switzerland which provides full flexibility to the operator in choosing parameter values with in a wide range. Plain brass wire of diameter 25μm is used as the tool material. De-ionized water is used as the dielectric. The electrical conductivity of the dielectric was maintained at 15 μS/cm. The temperature of dielectric was maintained at 22°C.

3.4 Planning of Experiments

The objective of conducting these experiments is to model the inter-relationship between the process parameters and performance measures in machining of these materials. In view of this, a systematic plan is made for conducting the experiments. Experiments will be conducted using response surface methodology. This section presents the details of the experimental plan.

3.5 Selection of Input Parameters

In the present research study, based upon the preliminary investigation, the following three process parameters i.e. Pulse on Time (T_{ON}), Pulse off Time (T_{OFF}), and Servo Reference Voltage (v) are chosen as input parameters (x_i).There are other factors which effect less significantly on the measures of performance, these are kept constant and called fixed factors.Thus, finally, three input parameters are selected for the designed experiments reported in the present chapter.

3.6 Design of Experiments

In the present study, experiments are designed on the basis of experimental design technique proposed by Box and Hunter (1957). The uniform-precision Titanium Alloy VT20 (BT20) has been used as the work piece material to

improve the reliability of the results and to reduce the size of experiments without loss of accuracy. The strategy of complete randomization is adopted for conducting the experiments. On the basis of extensive preliminary investigations, literature and the experience of machine operators input parameters (control factors) are selected to develop empirical models for WEDM in machining of Titanium Alloys. Pulse on-time (μs), pulse off-time (μs) & Servo Reference Voltage (v) are selected as the input parameters. Table 2 shows the levels and range of these parameters for the experiments as well as their codes.

Table 2: Experimental Parameters Settings (Variable Parameters)

Ton: Pulse on-time (μs), T off: Pulse off-time (μs),
Aj: Servo Reference Voltage (v)

Level	Ton: Pulse on-time, A (μs)	Toff: Pulse off-time, B (μs)	Aj: Servo Reference Voltage (v)
+2	0.4	8	30
+1	0.6	10	35
0	0.8	12	40
-1	1.0	14	45
-2	1.2	16	50

The experimental matrix employed in this study is shown,

Table 3: Design Matrix (CCD)

Sr. No.	T-on (μs)	Aj (v)	T-off (μs)	Ra (μ)	CR (mm/min)
1	0.6	35	10	2.196	5.9
2	1	35	10	2.336	8.1
3	0.6	45	6	2.226	6.8
4	1	45	10	2.569	9.7
5	0.6	35	14	2.089	6.01
6	1	35	14	2.505	9.33
7	0.6	45	14	2.113	5.52
8	1	45	14	2.543	9.95
9	0.8	40	8	2.351	8.61
10	0.8	40	16	2.406	8.41
11	0.8	30	12	2.302	7.01
12	0.8	50	12	2.418	8.15
13	0.4	40	12	1.352	7.78
14	1.2	40	12	2.764	11.81
15	0.8	40	12	2.328	9.16
16	0.8	40	12	2.168	8.59
17	0.8	40	12	2.387	8.79
18	0.8	40	12	2.287	8.93
19	0.8	40	12	2.385	9.06
20	0.8	40	12	2.44	8.69

4. Results and Analysis

The Experimental results have been presented in table No. 3 The results have been analysed by using Analysis of Variance ANNOVA for the Cutting Rate and Surface Roughness are shown in table number 4 & 5

4.1 Analysis of Variance for Cutting Rate and Surface Roughness

The relative importance of the different parameters with respect to surface roughness and cutting rate was investigated to determine more accurately the significant parameters by using Annova. The result of Annova are presented in table 4 and 5

Table 4: Analysis of Variance for Cutting Rate

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	37.7385	4.1932	7.49	0.002
Linear	3	18.0802	6.0267	10.76	0.002
Ton	1	12.4547	12.4547	22.25	0.001
Aj	1	2.8423	2.8423	5.08	0.048
Toff	1	1.0096	1.0096	1.80	0.209
Square	3	7.9879	2.6626	4.76	0.026
Ton*Ton	1	0.4095	0.4095	0.73	0.412
Aj*Aj	1	4.7029	4.7029	8.40	0.016
Toff*Toff	1	2.6136	2.6136	4.67	0.056
2-Way Interaction	3	2.5907	0.8636	1.54	0.264
Ton*Aj	1	0.1161	0.1161	0.21	0.659
Ton*Toff	1	1.1526	1.1526	2.06	0.182
Aj*Toff	1	0.9359	0.9359	1.67	0.225
Error	10	5.5986	0.5599		
Lack-of-Fit	5	5.3576	1.0715	22.23	0.002
Pure Error	5	0.2410	0.0482		
Total	19	43.3371			
R-Square, Rsq = 87.08%					

Cutting Rate

Ton and Aj have been found significant on Cutting Rate. The model for cutting rate has also been found adequate [The adequacy of model was also tested by using analysis of residuals please refer to figure 4]

Table 5: Analysis of Variance for Surface Roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	1.28994	0.143327	8.25	0.001
Linear	3	0.76299	0.254330	14.64	0.001
Ton	1	0.71451	0.714510	41.12	0.000
Aj	1	0.00695	0.006951	0.40	0.541
Toff	1	0.00091	0.000905	0.05	0.824
Square	3	0.14894	0.049646	2.86	0.091
Ton*Ton	1	0.11149	0.111491	6.42	0.030
Aj*Aj	1	0.00240	0.002403	0.14	0.718
Toff*Toff	1	0.01325	0.013252	0.76	0.403
2-Way Interaction	3	0.02663	0.008878	0.51	0.684
Ton*Aj	1	0.01916	0.019160	1.10	0.318
Ton*Toff	1	0.00625	0.006247	0.36	0.562
Aj*Toff	1	0.00031	0.000310	0.02	0.896
Error	10	0.17374	0.017374		
Lack-of-Fit	5	0.12731	0.025462	2.74	0.146
Pure Error	5	0.04643	0.009287		
Total	19	1.46369			
R-Square, Rsq = 88.13%					

Surface Roughness

Ton and Ton^2 have been found significant on Surface Roughness. The model for surface roughness has also been found adequate [The adequacy of model was also tested by using analysis of residuals please refer to figure 5]

4.2 Regression

Based upon the experimental results empirical relation equations of cutting rate and surface roughness have been developed using regression analysis. The equation of the cutting rate & surface roughness are as shown

CR = -36.9 - 14.5 Ton + 1.721 Aj + 2.19 Toff + 3.15 Ton*Ton - 0.01710 Aj*Aj - 0.0680 Toff*Toff + 0.127 Ton*Aj + 0.885 Ton*Toff - 0.0319 Aj*Toff --------------- I

The correlation of cutting rate has been found to be in good agreement with the experiment results. The r square value of cutting rate equation is 87.08%.

Ra = 3.25 + 1.15 Ton - 0.061 Aj - 0.139 Toff - 1.646 Ton*Ton + 0.00039 Aj*Aj+ 0.00484 Toff*Toff --- II

The correlation of surface roughness has been found to be in good agreement with the experiment results. The r square value of surface roughness equation is 88.13%.

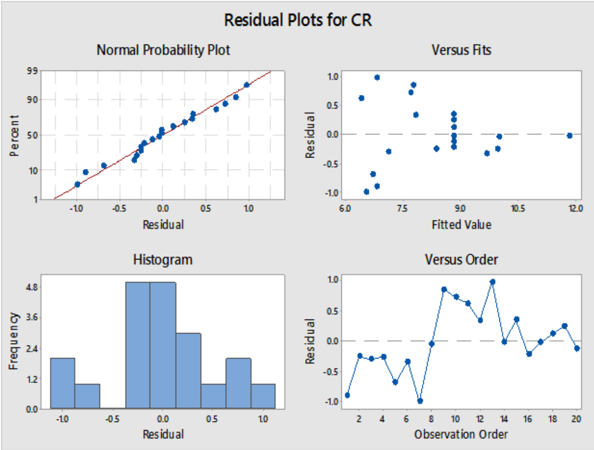

Figure 1: Residual Plots for CR

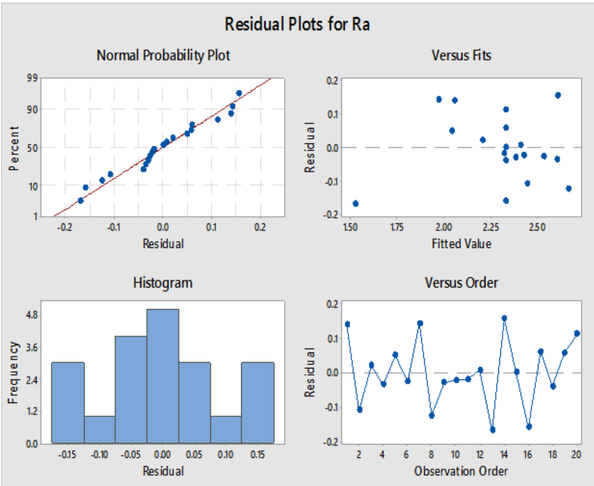

Figure 2: Residual Plots for Ra

4.3 The effect of Process Parameters

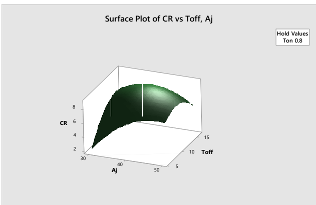

Figure 3: Surface Plot of CR vs Toff & Aj

The effect of Servo voltage (Aj) and Pulse off Time (Toff) is shown in the figure No.3. Cutting Rate (CR) was observed to be increased in Servovoltage at low value of Toff. However at high value of Toff, Cutting Rate was reletively constant inspite of increasing Servo voltage. This can be due to interaction between Aj & Toff.

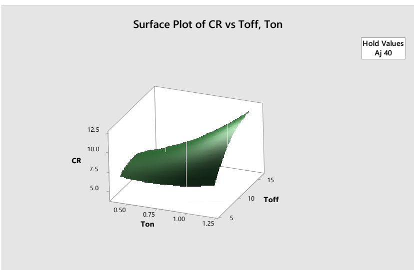

Figure 4: Surface Plot of CR vs Toff & Ton

The effect of Pulse on Time (Ton) and Pulse off Time (Toff) is shown in the figure No.4. Cutting Rate (CR) was observed relatively constant in Ton at low value of Toff. However at high value of Toff, Cutting Rate was observed to be increased inspite of increasing Ton. This can be due to interaction between Ton & Toff.

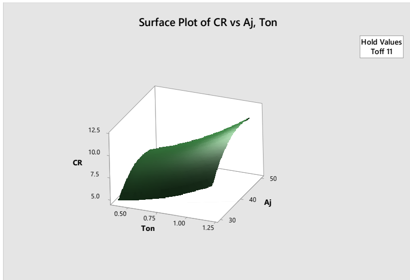

Figure 5: Surface Plot of CR vs Aj & Ton

The effect of Pulse on Time (Ton) and Servo Voltage (Aj) is shown in the figure No.5. Cutting Rate (CR) was observed to be slowly increased in Ton at low value of Aj. However at high value of Aj, Cutting Rate was observed to be increased inspite of increasing Ton. This can be due to interaction between Ton & Aj.

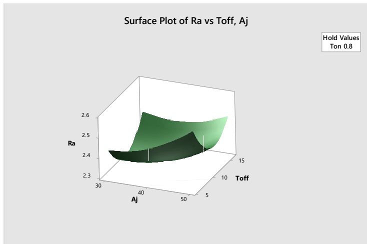

Figure 6: Surface Plot of Ra vs Toff & Aj

The effect of Servo voltage (Aj) and Pulse off Time (Toff) is shown in the figure No.6. Surface Roughness (Ra) was observed to be increased in Servovoltage at low value of Toff. However initially Ra was increased at low value of Toff, decreased at mid of Toff & reletively increased at high value of Toff inspite of increasing Servo voltage. This can be due to interaction between Aj & Toff.

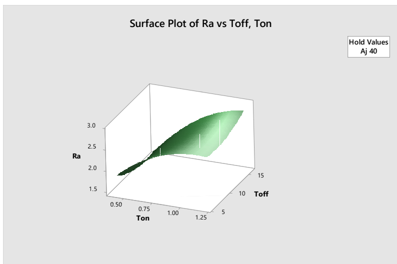

Figure 7: Surface Plot of Ra vs Toff & Ton

The effect of Pulse on Time (Ton) and Pulse off Time (Toff) is shown in the figure No.7. Surface Roughness (Ra) was observed to be increased in Ton at low value of Toff. However at high value of Toff, Surface Roughness was was reletively constant inspite of increasing Ton. This can be due to interaction between Ton & Toff.

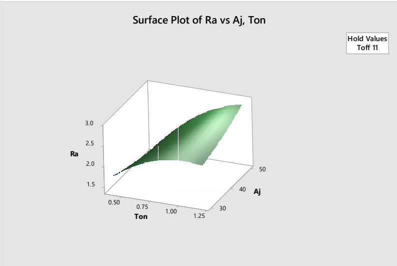

Figure 8: Surface Plot of Ra vs Aj & Ton

The effect of Pulse on Time (Ton) and Servo Voltage (Aj) is shown in the figure No.8. Surface Roughness (Ra) was observed to be slowly increased in Ton at low value of Aj. However at high value of Aj, Surface Roughness was observed to be increased inspite of increasing Ton. This can be due to interaction between Ton & Aj.

5. Conclusion

Wire electrical discharge machining of Ti alloys has been undertaken in the present study. In this paper influence of process parameters on metal removal rate and surface roughness is investigated. The parameters and their combinations affecting the process were obtained using RSM. Based upon the experimental investigations following conclusions can be drawn,

- Servo voltage and pulse on time were found to be significant on cutting rate. Moreover square term such as Ton^2, Aj^2 and $Toff^2$ were also found to affect the cutting rate significant.
- The surface roughness was found to be affected by pulse on time. However the effect of on time & Ton^2 was significant.
- The Regression equations were found to be in good agreement with the experimental results with the r square value of 87.08% and 88.13% for the cutting rate and surface roughness respectively.

6. Acknowledgements

The authors are thankful to Mr. H.D. Kapse & Management of Indo German Tool Room, Aurangabad, India for providing Material & for the WEDM facility. The authors would like to acknowledge the help of Dr. Nilesh G. Patil, Vice Principal MIT, Aurangabad for his valuable guidance.

References

[1] Ho KH, Newman ST (2004) State of the art in wire electrical discharge machining (WEDM). International Journal of Machine Tools & Manufacture 44: 1247–1259

[2] S. Sarkar, S. Mitra, B. Bhattacharyya (2004) Parametric analysis and optimization of wire electrical discharge machining of titanium aluminide alloy. Journal of Materials Processing Technology 159: 286–294

[3] Liao YS, Huang JT, Su HC (1997) A study on machining parameters optimization of wire electrical discharge machining. Journal of Materials Processing Technology 71:487–493

[4] Shajan Kuriakose, M.S. Shunmugam (2004) Characteristics of wire-electro discharge machined Ti6Al4V surface. Materials letters 58:2231-2237

[5] Nilesh G. Patil & P. K. Brahmankar (2010) Determination of material removal rate in Wire Electro - discharge machining of metal matrix composites using dimensional analysis. International Journal of Manufacturing technology 51: 599–610

[6] S.L. Soo, M.T. Antara, D.K. Aspinwall, C. Sage, M. Cuttell, R. Perez, A.J. Winn (2013) The effect of wire electrical discharge machining on the fatigue life of Ti-6Al-2Sn-4Zr-6Mo aerospace alloy. The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM)

[7] Farnaz Nourbakhsh, K. P. Rajurkar, A. P. Malshe, Jian Cao (2013) Wire electro-discharge machining of titanium alloy. The First CIRP Conference on Bio manufacturing

[8] Neeraj Sharmaa, Rajesh Khanna, Rahuldev Gupta (2013) Multi Quality Characteristics of WEDM Process Parameters With RSM International Conference on Design and Manufacturing, IConDM.

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