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Optimization of cutting parameters for zirconium diboride (ZrB2) Using wire cut EDM

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Abstract

The Wire Electric Discharge Machining is a variation of EDM process and is commonly known as wire-cut EDM or wire cutting. In this process, a thin metallic wire is fed on-to the workpiece, which is submerged in a tank of dielectric fluid . Wire cutting EDM is used when lower residual stresses are desired, because it does not require high cutting forces for removal of material. WEDM has been adopted as a machining tool for die materials which require high strength and hardness as well as good resistance. Rough cutting operation in WEDM is treated as a challenging one because improvement of more than one machining performance measures i.e metal removal rate (MRR), surface finish (SF) and cutting width are sought to obtain a precision work. Using Taguchi's parameter design, significant machining parameters affecting the performance measures are identified as discharge current, pulse duration, pulse frequency, wire speed, wire tension, and dielectric flow. The relation between various control factors and responses like MRR, SF are established by means of nonlinear regression analysis, resulting in a valid mathematical model. The paper indicates that the process parameters can be adjusted to achieve better metal removal rate, surface finish and cutting width simultaneously.

Keywords: Wirecut EDM, Material Removal Rate, Surface Finish

INTRODUCTION

The machining industry is constantly in need for developing new machining methods, improving the existing techniques in the light of the high precision requirements in aerospace, automotive and defense industry. Manufacturing technology has evolved over the past few decades to cater to these needs, non-traditional machining methods being one such development. These machining methods have shown better results compared to their counterparts over the years, in terms of improved quality, work efficiency and scope for research and development.

Wire-EDM process with a thin wire as an electrode transforms electrical energy to thermal energy for cutting conductive materials. Ceramics and Alloy Steels can be machined irrespective of their hardness and toughness. The purpose of this paper is to investigate the influence of process parameters on Zirconium Diboride (ZrB2) for improving its surface roughness, cutting speed when machined on a wire-cut EDM. Process parameters chosen for the experiments were Pulse-on time (A**),** Pulse-off time(B)**,**Wire Speed (WS), and Average reference voltage (Aj). The experiments were designed based on Taguchi methodology. Further, experiments were conducted to conclude the significance of the chosen process parameters in terms of their effects on surface roughness. Conclusive results are henceforth discussed.

Principle

Wire cut EDM is a thermal erosion process wherein, material is melted and vaporized from an electrically conductive work piece immersed in a liquid dielectric. The workpiece (Cathode) and the tool (Anode) are separated by a specific gap called the spark gap. The voltage supply is pulsated as continuous voltage supply results in arc formation which leads to improper material removal. Hence pulsed arc discharges are applied in this gap.

Spark occurs wherever the gap between the tool and the work piece surface is smallest. After material is removed due to a spark, this gap increases and the location of the next spark shifts to a different point on the work piece surface. This ensures uniform material removal over the entire surface. The dielectric acts as an insulator until the breakdown voltage is achieved. Once the optimum voltage is attained, the dielectric strength breaks and the spark discharge occur for a certain time period after which the dielectric fluid flushes out the debris.

Process

The wire, which is constantly fed from a spool, is held between upper and lower guides. The guides and the table which are usually CNC-controlled move in the x-y plane. On most machines, the upper guides can also move independently in the z-u-v axis, giving rise to the ability to cut tapered and transitioning shapes. Most machines can cut tapers of 20-30 degrees depending on the work piece thickness. This allows the wire-cut EDM to be programmed to cut very intricate or complex shapes and delicate shapes.

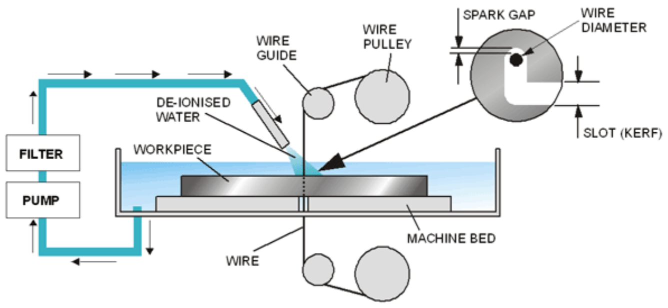

Figure 1: Process of WEDM

The work material used for this research is Zirconium Diboride (ZrB2)

Table 1: Composition of Zirconium Diboride (ZrB2)

Zirconium 83.60%	**Hafnium 0.82%**
Silicon 10.74%	**Molybdenum 0.76%**
Aluminum 2.75%	**Francium 0.10%**
Sulfur 1.17%	**Niobium 0.054%**

Zirconium diboride (ZrB_2) is a highly covalent refractory ceramic material with a hexagonal crystal structure. ZrB_2 is an ultra high temperature ceramic (UHTC) with a melting point of 3246 °C. This along with its relatively low density of ~6.09 g/cm^3 (measured density may be higher due to hafnium impurities) and good high temperature strength makes it a candidate for high temperature aerospace applications such as hypersonic flight or rocket propulsion systems. It is an unusual ceramic, having relatively high thermal and electrical conductivities.

Wire-Cut EDM Process Parameters for Experimentation

As the experiment proceeds a few parameters in a wire cut EDM have been identified to have more effect on the work piece over the other parameters. These parameters are varied according to the experimental design to achieve better surface finish. The parameters are:

Pulse on time (A): For Iso frequency mode longer pulse duration increases the material removal rate. However short pulse duration is preferred under Iso pulse condition as long pulse duration causes the plasma channel to expand resulting in less energy density on the work material, which is not sufficient to melt and vaporize the work material.

Pulse off time (B): It affects the speed and stability of the cut. Large pulse off duration reduces the spark concentration thereby decreasing the material removal rate whereas short pulse off results in improper flushing and probability of arcing.

Wire speed: The wire speed has a direct influence on the surface finish of the machined work piece. The higher speed will result in rough surface and less speed of the wire will result in finer finish of the work-piece.

EXPERIMENTATION AND METHODOLOGY

Process parameters selection:

The process objectives are the target values for this experiment are surface roughness and cutting speed. Surface roughness is analyzed using the minimization of S/N ratio and cutting speed is analyzed using the maximization of S/N ratio. The parameters pulse-on time (A), pulse-off time (B), Wire speed (WS) and average reference voltage (Aj) were chosen for the experiment as they were found to have profound effect on surface roughness and cutting speed.

Orthogonal array selection:

The level of experimentation is then concluded based on level of precision desired. 4-level experimentation was employed with the limits of parameters confined by the specifications. Based on the level of experimentation and the number of parameters, the orthogonal array i.e. L9 was selected from the array selector matrix.

Pre-machining:

The finished billet and ground to be machined on Wire-cut EDM to the following specifications.

Number of specimens: 9

Specimen dimensions: $10\times 5 \times 30\ mm$

Experimentation:

Nine experiments were conducted on Wire-cut EDM based on the runs derived from the orthogonal array. The cutting speeds for each of those experiments were recorded. All the nine specimens were subjected to surface roughness tests and the results were recorded in terms of Ra and Rz.

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Analysis:

The data recorded was analyzed using the S/N ratios to determine the combination of process parameters to reduce the surface roughness and improve the cutting speed. Further experiments were conducted on the specimens to verify the results.

Experimentation on Wire-cut EDM

The nine combinations of process parameters were first subjected to trial runs according to L9 orthogonal array table to check the viability of the experiments without hindrances. In the course of the trial runs the limits of the parameters chosen were finalized by eliminating the levels which were not feasible.

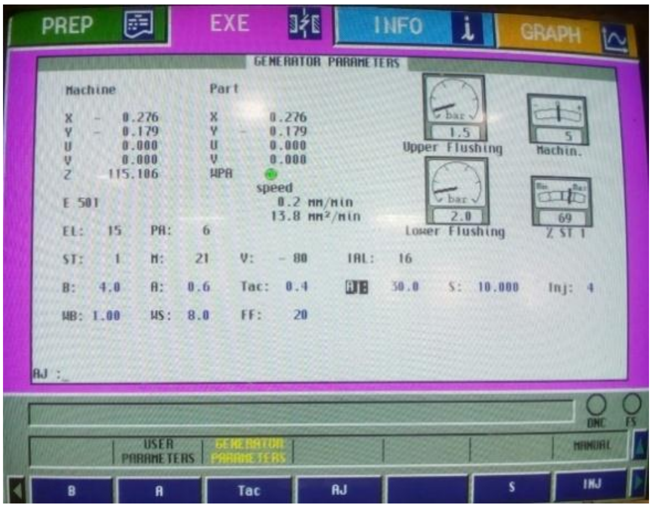


Figure 2: Process parameter screen

Table 2: Levels of Parameters

Parameters	Level-1	Level-2	Level-3
A (µs)	0.6	0.8	1.0
B (µs)	4	6	8
WS (m/min)	8	10	12
Aj (volts)	30	45	60

The nine specimens were then subjected to wire electrical discharge machining to the specified dimensions.

Table 3: L9 Orthogonal Array

Runs	P1	P2	P3	P4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 4: L9 with parameters

Runs	A	B	WS	Aj
1	0.6	4	8	30
2	0.6	6	10	45
3	0.6	8	12	60
4	0.8	4	10	60
5	0.8	6	12	30
6	0.8	8	8	45
7	1.0	4	12	45
8	1.0	6	8	60
9	1.0	8	10	30

The input parameters which were kept constant for all the nine runs are:

- Tac: 0.4µs
- V: -80 volts
- IAL: 16 A
- FF: 20
- Inj: 4 bar

METHODOLOGY

Each specimen is placed on the worktable under the diamond stylus and the cutoff wavelength, measurement length is set 4mm (ISO 4288:'96) to determine the surface roughness. The surface roughness's of the machined surface are measured and their mean is calculated.

RESULTS AND DISCUSSION

Surface Roughness (Ra): The Ra values of all the specimens on all their machined surface are tabulated and their mean is calculated which is further used to calculate the S/n ratios.

Sample Calculations for Surface Roughness (Ra)

Specimen 1: Ra values of specimen 1

Ra (μm)			
1	**2**	**3**	**Average(mean)**
1.16	**1.14**	**1.24**	**1.18**

Ra **(Average)** $=\frac{1.16+1.14+1.24}{3}$ **=1.18**μm

S/N Ratio calculation for Ra:

$$SN_i = -10\log\left(\sum_{u=1}^{N_i}\frac{y_u^2}{N_i}\right)$$

S/N ratio =-10 log $\frac{1.16^2+1.14^2+1.24^2}{3}$ **=-1.44**

Table 5: S/N ratios for Ra values

Runs	Ra (μm)				Variance	S.D	S/N ratio
	1	2	3	Average			
1	1.16	1.14	1.24	1.180	0.0018	0.0000032	-1.4434
2	1.22	1.23	1.40	1.280	0.0068	0.000046	-2.1847
3	1.26	1.14	1.16	1.186	0.0027	0.0000072	-1.4950
4	1.38	1.22	1.18	1.233	0.0080	0.000064	-2.0277
5	1.26	1.28	1.22	1.253	0.0006	0.00000036	-1.9630
6	1.32	1.30	1.35	1.323	0.0004	0.00000016	-2.4344
7	1.40	1.40	1.44	1.413	0.0003	0.00000009	-3.005
8	1.25	1.37	1.32	1.313	0.0024	0.0000057	-2.3735
9	1.37	1.34	1.45	1.386	0.0021	0.0000044	-2.8443

S/N ratios of Surface Roughness (Rz):

The Rz values of all the specimens on all their machined surfaces are tabulated and their mean is calculated which is further used to calculate the S/N ratios.

Rz values of specimen 1

Rz (μm)			
1	**2**	**3**	**Average(mean)**
6.75	**6.88**	**7.52**	**7.05**

Rz (Average)= $\frac{6.75+6.88+7.25}{3}$ **=7.05**μm

S/N Ratio calculation for Rz:

S/N ratio = -10 log $\frac{6.75^2+6.88^2+7.25^2}{3}$ **= -16.9736**

Table 6 : S/N ratios for Rz values:

Runs	Rz (μm)				S/N ratio
	1	2	3	Average(mean)	
1	6.75	6.88	7.52	7.05	-16.9736
2	7.11	7.95	8.05	7.70	-17.7465
3	7.71	7.58	7.19	7.49	-17.4972
4	8.24	7.22	6.80	7.42	-17.4368
5	7.55	7.65	7.24	7.48	-17.4803
6	8.09	7.35	8.03	7.82	-17.8758
7	7.83	7.97	8.36	8.05	-18.0591
8	7.25	8.05	7.83	7.71	-17.7493
9	8.13	8.54	8.36	8.34	-18.4285

S/N ratios of Cutting Speed (CS)

The Cutting speeds of all the specimens are calculated for the first three machined surfaces each of length 10mm. The cutting time, speed of the last machined surface was neglected as it is an accelerated cut resulting in higher surface roughness.

The nine cutting speed values are tabulated and their mean is calculated which is further used to calculate the S/N ratios.

Cutting Speed values of specimen 1

Cutting Speed-CS (mm/min)			
1	**2**	**3**	**Average**
0.7	**0.7**	**0.7**	**0.7**

CS (Average) $=\frac{0.7+0.7+0.7}{3}$ **=0.7 mm/min**

S/N Ratio calculation for CS:

S/N ratio = -10 log$\frac{0.7^2+0.7^2+0.7^2}{3}$ **=3.098**

Table 7: S/N ratios for Cutting Speeds

Runs	Cutting time (mm)	Cutting speeds (mm/min)				S/N ratio
		1	2	3	Average	
1	13.33	0.7	0.7	0.7	0.7	3.098
2	27.44	0.4	0.3	0.4	0.36	8.643
3	12.12	0.1	0.1	0.1	0.1	20.00
4	33.22	0.4	0.3	0.4	0.36	8.643
5	14.42	0.6	0.6	0.7	0.63	3.943
6	32.07	0.3	0.2	0.2	0.23	12.46
7	14.07	0.7	0.8	0.8	0.76	2.291
8	21.29	0.3	0.3	0.3	0.3	10.457
9	18.00	0.5	0.6	0.6	0.56	4.903

Influence of Process Parameters

Surface Roughness (Ra) – Sample Calculation for Wire speed under Ra

Table 8: Selection of S/N ratios for each level

Runs	A	B	WS	Aj	S/N Ratio
1	1	1	1	1	-1.443
2	1	2	2	2	-2.184
3	1	3	3	3	-1.495
4	2	1	2	3	-2.027
5	2	2	3	1	-1.963
6	2	3	1	2	-2.434
7	3	1	3	2	-3.005
8	3	2	1	3	-2.373
9	3	3	2	1	-2.844

$$S/N\ 1 = \frac{(-1.443)+(-2.434)+(-2.373)}{3} = -2.083$$

$$S/N\ 2 = \frac{(-2.184)+(-2.027)+(-2.844)}{3} = -2.351$$

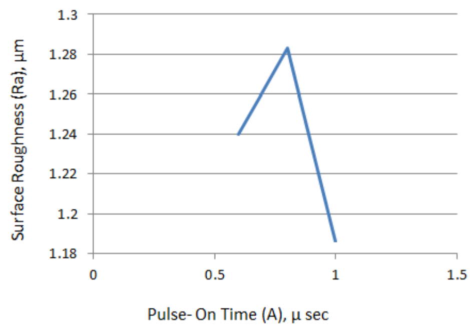
$$S/N\ 3 = \frac{(-1.495)+(-1.963)+(-3.005)}{3} = -2.154$$

Range = (- 2.083)- (- 2.351) = 0.268

The S/N ratios for all the other parameters are calculated in the similar manner and their ranges are calculated to rank them and conclude their predominant affect in the decreasing order. The ranks are established based on the increasing order of S/N ratios i.e., larger the range, larger the effect on the process objective.

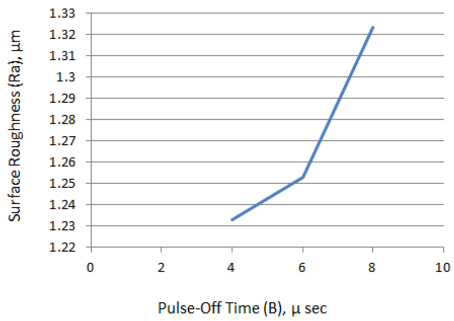
Influence of process parameters on Surface Roughness (Ra)

The relationship between the process parameters and the surface roughness (Ra) is established by plotting the experimental data.



Pulse-On time (A) Vs. Surface Roughness

From the above fig the minimum value o Pulse-on time i.e. A = 0.6 s is taken as the Pulse-on time value for further experiments conducted to improve the Surface Roughness (Ra). At A =0.6 sec, 0.8 sec, points of inflexion were observed indicating a variation in the surface roughness trends.



Pulse-Off time (B)Vs. Surface Roughness

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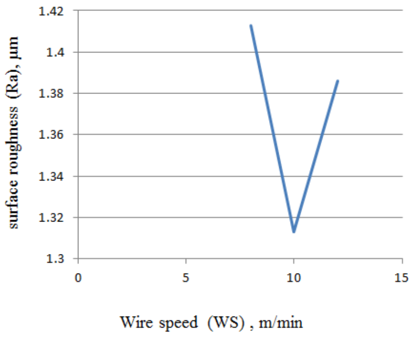
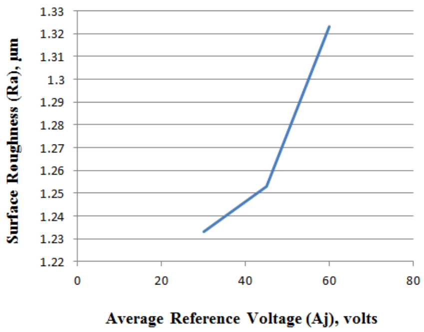
From the above fig the minimum value of Pulse-Off time i.e. B = 4s is taken as the Pulse-Off time value for further experiments conducted to improve the Surface Roughness (Ra). This is clearly a point of inflexion which results in minimum surface roughness.



Wire Speed (WS) Vs.Surface Roughness (Ra)

From the above fig the minimum value of Wire Speed i.e. WS = 8 cm/min is taken as the Wire speed value for further experiments conducted to improve the surface roughness (Ra). This is clearly a point of inflexion which results in minimum surface roughness.



Average reference voltage (Aj) Vs. Surface Roughness (Ra)

From the above fig the minimum value of Average reference voltage i.e. Aj = 60 is taken as the average reference value for further experiments conducted to improve the surface roughness (Ra).

The following parameters values deduced from the relationships between the process parameters and the surface roughness (Ra) are found to confirm with the values deduced from the S/N ratios.

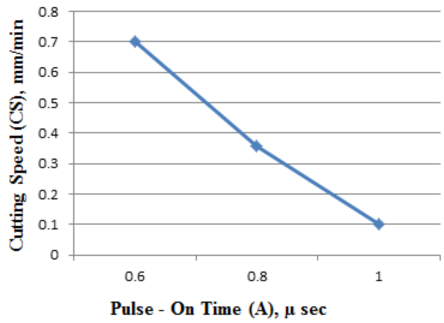
Table Process Parameters combination to improve Surface Roughness (Ra)

Parameters	values
A	0.6 sec
B	4 sec
WS	8 cm/min
Aj	60 v

Influence of process parameters on cutting speed

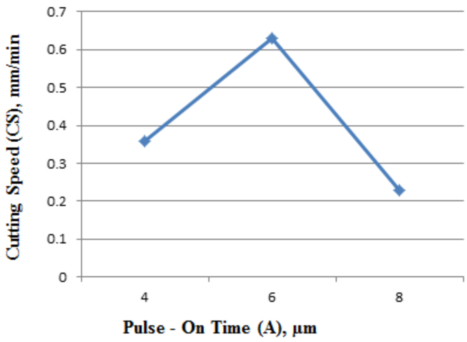
The relationship between the process parameters and the cutting speed (CS) is established by plotting the experimental data.

Pulse-On Time (A) Vs. Cutting speed (CS)



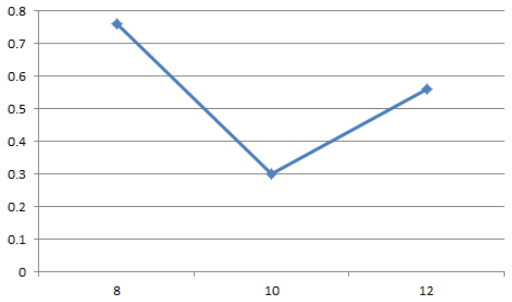
From the above fig the maximum value of Pulse-on time i.e. A =1.0 sec, is taken as the pulse-on time value for further experiments conducted to improve the cutting speed (CS).

Pulse-Off Time (B) Vs. Cutting speed



From the above fig the maximum value of the Pulse-Off time i.e. B = 4 sec is taken as the Pulse-Off time value for further experiments conducted to improve the cutting speed (CS).

Wire Speed (WS) Vs. Cutting speed (CS)

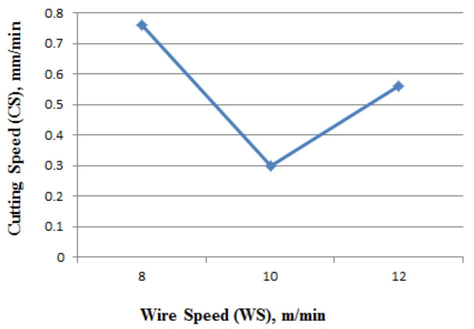


X-axis: Wire speed (WS), cm/min

Y-axis: Cutting speed (CS), mm/min

From the above fig the maximum value of Wire speed i.e. WS = 10cm/min is taken as the Wire speed value for further experiments conducted to improve the Cutting speed (CS).

Average reference voltage (Aj) Vs. Cutting speed



From the above fig the minimum value of Average reference voltage i.e. Aj = 30v is taken as the average reference voltage for the further experiments conducted to improve the cutting speed (CS). This is clearly a point of inflexion which results in maximum cutting speed.

The following parameters values deduced from the relationship between the process parameters and the cutting speed are found to conform the values deduced from the S/N ratios.

Process parameters combination to improve the Cutting Speed (CS)

Parameters	Values
A	1.0
B	4
WS	10
Aj	30

CONCLUSIONS

- The paper presents an attempt to identify the process parameters which affect the surface roughness of the material Zirconium Diboride (ZrB2) when working on Wire cut EDM.
- The aim of the project was to bring down the stages of machining. This investigation has brought down the 3 stages of machining roughing, semi – finishing and finishing to 2 stages i.e. roughing and finishing. The semi- finishing stage can thus be eliminated.
- The Taguchi's methodology has been used to find out the parameters affecting the surface roughness and the cutting speed. The responses like Ra, Rz and are considered for surface roughness. Critical process parameters such as pulse on time, pulse off time, wire tension and average reference voltage are considered to evaluate surface roughness and cutting speed.
- The experiments were conducted using L9 orthogonal array with 3 levels and 4 parameters on Robofil wire cut EDM. The cutting time for each cut is noted down and the cutting time is calculated. The surface finish factor (Ra and Rz) are measured on Surfcom measuring device model 1900SD3 and the values are analyzed.
- The range of effect of individual parameters on the surface roughness is found out and they have been ranked accordingly.
- S/N Ratios, Average analysis is used to analyze the values obtained during the experiment and the parameters are selected to yield better results.

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