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Multi-Objective Optimization in WEDM Process of Titanium Alloy (Ti-3Al-2.5V-2.0WC) using Desirability Approach

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Abstract

Recently, Titanium alloy (Ti-3Al-2.5V) reinforced with Tungsten Carbide (Ti-3Al-2.5V-2.0WC) developed using the microwave sintering process has plays a major role in mining industry. It has very good mechanical property and corrosion resistance. Due to its better strength and high melting point, it is difficult to machine in conventional machining process. Therefore, WEDM process give the solution to cut this high strength material in an effective manner. In this present work, the WEDM input variables such as Servo Voltage (SV), Pulse Time - On (PT-ON), Pulse Time – Off (PT-OFF) and Cutting Speed Percentage (CSP) are considered. L09 Orthogonal Array Matrix (OAM) is considered for experimental work. The output variables like Material Removal Rate (MRR) and Surface Roughness (SR) are considered to obtained the quality machining process. Multi objective optimization technique like Taguchi-Desirability Approach method is implemented to find the optimum input variables. The Improvement of MRR from 0.05978 g/min to 0.06420 g/min and SR from 3.812 µm to 3.452 µm are obtained using Desirability Approach.

Keywords: *Desirability Approach, MRR and SR, Titanium Alloy, WEDM Process*

1.0 Introduction

Titanium based alloys have very good mechanical properties especially high strength, good weldability and corrosion resistance property. Also, due to its good weight ratio and good mechanical properties it is highly recommended in mining industry applications. But it has poor machinability characteristics due to its high melting point range. Therefore, it is very difficult to machine in conventional machining processes. To overcome this issues, thermal energy based advanced machining technique like Wire cut Electrical Discharge Machining (WEDM) Process is highly recommended to cut the Titanium based alloy[1,2]. Taguchi - Orthogonal Array is implemented to conduct the experiments in WED machine. The optimal combinations of WEDM process variables found using the optimization techniques[3]. Multiple responses characteristics measured using the multi objective optimization methods. In this, Taguchi Grey analysis is implemented to find the optimum input

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variables to obtain the multiple characteristics like Kerf width, Material Removal, Electrode wear and Surface roughness while machining Titanium alloy (Ti-6Al-4V) in WEDM process[4,5]. To obtain the better and accurate multiple characterizes improvement, Response surface methodology is used[6]. The influence of the process parameters on multiple outcomes such as MRR and SR were obtained using the 3D surface plots. Also, desirability function technique is used for finding optimum input process variables while machining α-β Titanium Alloy[7].

Material Removal Rate and Surface Roughness were increases when peak current and pulse-off time increased[8]. Similarly, pulse on time and pulse off time were influences more on kerf width and MRR while machining thin sheet titanium alloy in WEDM process[9]. Also, three output variables such as kerf width, cutting speed and SR were improved tremendously using desirability function approach technique while machining Ni-Ti alloy[10].

The output variables such as cutting speed, SR and MRR were improved better by optimum input process variables by various optimization techniques such as utility approach and RSM -GRG technique[11,12]. But CS increases with peak current whereas SR decreases with decrease in pulse interval for the titanium alloy in WEDM process[13]. The surface quality of the machined titanium alloy specimens of optimized condition gives better quality[14,15].

Therefore, from the overall literature survey, no study is carried out on the newly developed Titanium alloy (Ti-3Al-2.5V) reinforced with Tungsten Carbide (Ti-3Al-2.5V-2.0WC) material in WEDM process. Due to its high strength, it has more challenges to cut in nontraditional techniques. Also, the novelty of the present work shows that implementation of desirability approach to find the better output variables to improve the productivity and quality finish parts in mining industry.

2.0 Materials and Methods

In this present machining study, Titanium alloy (Ti-3Al-2.5V) reinforced with Tungsten Carbide (Ti-3Al-2.5V-2.0WC) developed using the microwave sintering process is taken for the machining study. The various percentage composition of Tungsten Carbide was added in sintering to get fine metal alloy for aerospace tools applications. Out of the various composition of Tungsten Carbide final material, the high strength Ti-3Al-2.5V-2.0WC composition material taken for the machining study. A Ti-3Al-2.5V-2.0WC of 10mm diameter with 80 mm long shaft is taken for machining study. Due to its high strength, an effective machining process like Wire cut Electrical Discharge machining method is introduced to machine the Ti-3Al-2.5V-2.0WC alloy material. The physical properties of Ti-3Al-2.5V-2.0WC material is shown in Table 1.

Also, the image of the machined Ti-3Al-2.5V-2.0WC workpiece in Sprintcut WED machine is shown in Figure 1. The selection of the WEDM input variables has based

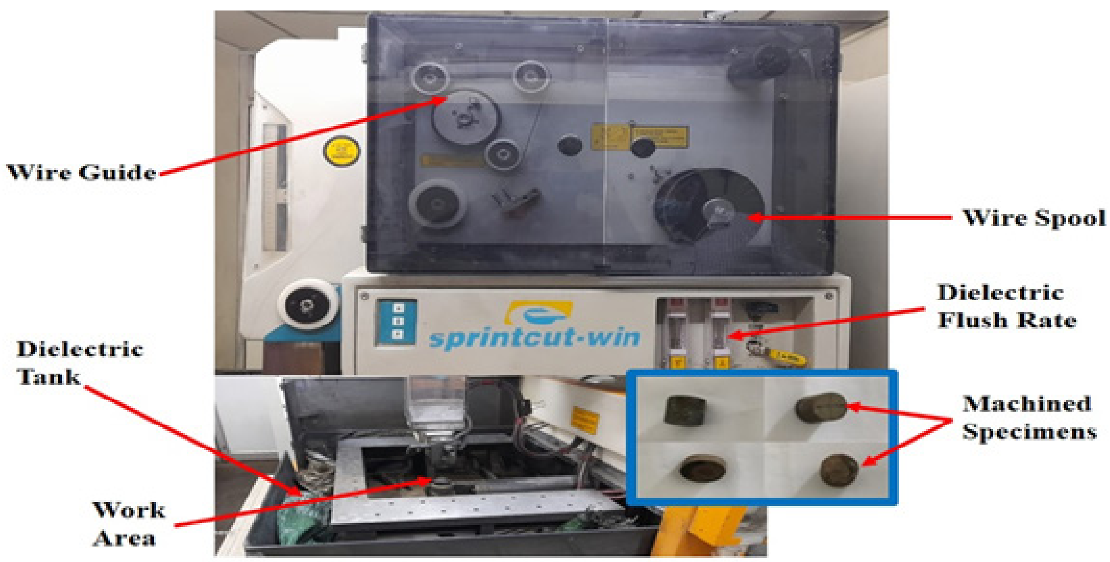

Figure 1. Sprintcut WEDM setup with Titanium alloy machined samples.

Table 1. Physical Properties of Ti-3Al-2.5V-2.0WC alloy

S. No.	Physical property	Titanium
1	Melting Point ˚C	1660
2	Density g/cc	4.5
3	Thermal conductivity at 20˚C , W/mK	17
4	Specific heat at 50˚C J/kgK	528
5	Coefficient of thermal expansion 10^{-6} /K	8.9
6	Elastic modulus GPa	105

Table 2. WEDM Input variables with levels

Input Variables	Symbol	Level 1	Level 2	Level 3	Unit
Servo Voltage (SV)	A	35	40	45	V
Pulse Time - On (PT-ON)	B	119	120	121	μs
Pulse Time – Off (PT-Off)	C	43	44	45	μs
Cutting Speed Percentage (CSP)	D	20	25	30	%

Table 3. L9 Orthogonal array matrix with input variables

Exp. No.	Servo Voltage (V)	Pulse Time On (μs)	Pulse Tim Off (μs)	Cutting Speed Percentage (%)
1	35	119	43	20
2	35	120	44	25
3	35	121	45	30
4	40	119	44	30
5	40	120	45	20
6	40	121	43	25
7	45	119	45	25
8	45	120	43	30
9	45	121	44	20

on the prior investigation study and literature survey. The input variables with 3 levels each has mentioned in Table 2.

Based on the selected input variables with levels, Taguchi Orthogonal Array Matrix (OAM) is developed using the Minitab 19 software. L9

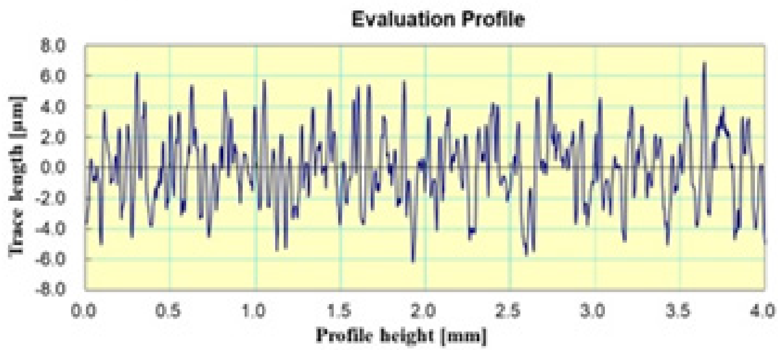

Figure 2. Surface roughness image of Sample no. 1.

Table 4. Taguchi OAM of input variables and output variables

Exp. No.	Servo Voltage (V)	Pulse Time - ON (μs)	Pulse Time - OFF (μs)	Cutting Speed Percentage (%)	MRR (g/ min)	SR - R_a (μm)
1	35	119	43	20	0.03825	3.883
2	35	120	44	25	0.04360	3.863
3	35	121	45	30	0.04750	3.798
4	40	119	44	30	0.06208	4.034
5	40	120	45	20	0.05541	4.008
6	40	121	43	25	0.03420	3.414
7	45	119	45	25	0.05463	4.059
8	45	120	43	30	0.04071	3.641
9	45	121	44	20	0.05978	3.812

Taguchi OAM is selected to conduct the experimental study in Sprintcut WEDM. L9 OAM is shown in Table 3.

In WEDM, experiments were carried out based on the above Table 3. Each experiments selected Input variables gets vary to find the output variables like Metal Removal Rate (MRR) and Surface Roughness (SR). Also, few input variables which has not selected also set at the optimum levels of every experiment has conducted. A 0.28mm coated brass wire is selected for the machining study. The constant input variables like dielectric flushing rate-, Gap Voltage as 55 V, Current rate 1.2A, Wire Feed rate as 4mm/min and Wire Tension as 1300 g were set at optimum levels. The MRR output variable for each experiment is calculated based on the weighing method. During machining process, the wire gets moves towards the Ti-3Al-2.5V-2.0WC workpiece to remove the material. Weighing method of before and after machining of weight calculation has been used to calculate the Metal Removal Rate (MRR). Similarly, after machined the Surface Roughness (SR) is calculated using the Mitutoyo 400 surface roughness tester machine. This tester instrument is used to calculate the roughness value of the all the nine specimens. In roughness tester machine, diamond tip is travelled along the machined sample to calculate roughness value in micrometer (μm) range. The image of roughness for sample 1 is shown in Figure 2. Finally, calculated output variables such as MRR and R_a were shown in Table 4.

2.1 Methodology

In this work, Multi Criteria Decision Methodology (MCDM) of Desirability Approach is implemented to obtain the optimum input variables for the various output variables in WED machining of Ti-3Al-2.5V-2.0WC alloy. Desirability approach has multiple steps to be followed.

Step 1: Making a decision matrix to show the output variables in relation to various input variables after identifying the goals and its attributes.

Step 2: To calculate the Desirability Index (DI) value for individual output variables. The value of DI depends on the output variables.

DI for MRR which is "Larger the Better" is calculated using the below Eq. (1).

$$\text{DI for MRR} = (X-X_{min})/(X_{max}-X_{min}) \quad (1)$$

where, DI – Desirability Index of MRR.

x_{max} and x_{min} are maximum and minimum value of MRR.

$$\text{DI for SR} = (X - X_{max})/(X_{min} - X_{max}) \quad (2)$$

where, DI – Desirability Index of SR.

x_{max} and x_{min} are maximum and minimum value of SR.

Step 3: Multiplying the desirability index of MRR and SR and power the value to get the Coefficient grade of Desirability (CD).

$$CD = (DI_1^{w1} * DI_2^{w2} * DI_3^{w3} * \ldots\ldots\ldots\ldots * DI_n^{wn})^{1/w} \quad (3)$$

where, DI – individual desirability index

wn = weight assigned to individual output variable

w = sum of individual weights.

With respect to the Coefficient grade of Desirability values rank can be assigned based on descending order to find the optimum setting of input variables for the multiple outcome variables.

3.0 Results and Discussion

By using the Desirability Approach the optimum combination of input variables for the multiple outcome variables are determined successfully. From the various outcome variables, larger the better was considered for MRR and smaller the better was considered for SR respectively. Desirability Index (DI) for the output variables such as MRR and SR were calculated using the Eqs. 1 and 2 as tabulated in Table 5. Also, Coefficient of Desirability (CD) is calculated using the Eq. 3 and it is tabulated in Table 5. Finally, ranking was done on the descending order of the CD values. Here, Experiment

Table 5. Optimization by desirability approach

Ex. No.	Individual Desirability		Multiplying	CD	RANK
	MRR (g/min)	SR (µm)			
1	0.1452	0.2729	0.0396	0.1990	6
2	0.3369	0.3039	0.1024	0.3200	4
3	0.4767	0.4047	0.1929	0.4392	2
4	0.9993	0.0388	0.0387	0.1968	7
5	0.7602	0.0791	0.0601	0.2452	5
6	0.0000	1.0000	0.0000	0.0000	9
7	0.7323	0.0000	0.0000	0.0000	8
8	0.2333	0.6481	0.1512	0.3889	3
9	**0.9168**	0.3829	0.3511	0.5925	1

Figure 3. Main effect for SN ratios of MRR.

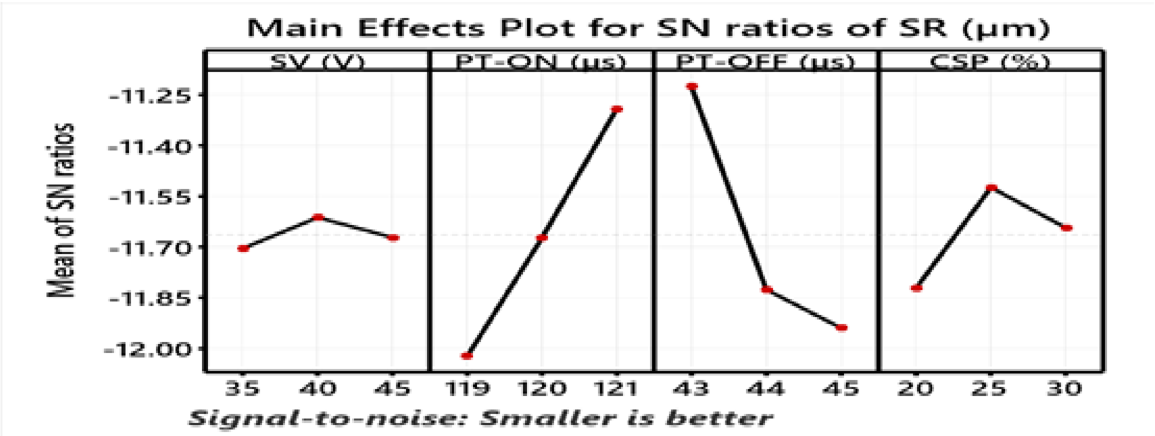

Figure 4. Main effect for SN ratios of SR.

Number 9 shows the optimized result which has highest CD value of **0.5925**. Hence from Table 5, the optimum input variables for the multiple output variables are Servo Voltage = 45 V, Pulse Time – On = 121 µs Pulse Time – Off = 44 µs and Cutting Speed Percentage = 20%.

After finding the overall optimum condition by Desirability Approach, the individual optimum setting conditions for the MRR and SR to calculated using the Taguchi Signal to Noise ratios approach which is single quality finding approach. Taguchi main effect plots for SN ratios of maximum MRR and minimum SR correspondence to the WEDM input variables were shown in Figures 3 and 4 respectively. From Figure 3, for higher the MRR, WEDM input variables levels combinations were Servo Voltage = 45 V, Pulse Time – ON = 121 µs, Pulse Time – OFF = 44 µs and Cutting Speed Percentage = 20%. Also from Figure 4, WEDM input variables levels combinations for smaller SR were Servo Voltage = 40 V, Pulse Time – ON = 121 µs, Pulse Time – OFF = 43 µs and Cutting Speed Percentage = 25%. Hence the individual optimum combinations were found using the Taguchi approach successfully.

3.1 Confirmation Tests

From Table 5, it is clearly indicated that experiment Number 9 shows the highest coefficient of desirability which has the better optimum WEDM input variables. Therefore, the combination of the input variables levels was Servo Voltage = 40 V, Pulse Time – ON = 121 µs, Pulse Time – OFF = 43 µs and Cutting Speed Percentage = 25% for the multiple output variables such as MRR and SR. Hence confirmation tests were carried out to

Table 6. Conformity tests

	Taguchi-Desirability Approach	Conformity Tests
Optimum Result	A3-B3-C2-D1	A3-B3-C2-D1
Average MRR	0.05978	0.06420
Average SR	3.812	3.452

find the optimum output variables for WEDMed Ti-3Al-2.5V-2.0WC alloy. Table 6 shows the conformity tests results which revealed that improvement in MRR and SR quality.

4.0 Conclusion

The investigation of the machining characteristics of Titanium alloy reinforced with Tungsten Carbide (Ti-3Al-2.5V-2.0WC) in Wire cut Electrical Discharge Machining was successfully carried out. Hence, the following conclusions are drawn,

- An ease statical calculation of Desirability Approach is implemented to found the better optimum input variables for both the MRR and SR respectively.
- Experiment number 9 shows the better optimum input variables levels with respect to highest Coefficient grade of Desirability which identified the Servo Voltage = 40 V, Pulse Time – ON = 121 µs, Pulse Time – OFF = 43 µs and Cutting Speed Percentage = 25 % for multiple output variables.
- Taguchi SN ratios gave optimum input variables for individual output variable.
- The optimum combination of A3-B3-C2-D1 by Desirability Approach shown the improvement in MRR from 0.05978 g/min to 0.06420 g/min where SR from 3.812 µm to 3.452 µm.

The MCDM optimized technique proposed to find the better optimum input variables to multiple output variables. It helps to improve the productivity and quality finish Ti-3Al-2.5V-2.0WC parts in Mining Industry.

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