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Expermental Investigation in Machining of CP Titanium Grade-2 by Wire EDM

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Abstract
Wire Electric Discharge Machining (WEDM) is electrical machining process with a thin wire as an electrode transforms electrical energy to thermal energy for cutting materials. The objective of this project is to study the effect of machining parameters of Wire Electrical Discharge Machining (WEDM) on CP Titanium Grade- 2 which are now widely used in many medical, aerospace applications due to their high technical benefits using Taguchi method to achieve lower surface roughness (Ra). Hence, non-traditional machining methods including electrochemical machining, ultrasonic machining, Electrical Discharging Machine (EDM) etc. are applied to machine such difficult to machine materials. Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. On the other hand, roughness may promote adhesion. Although a high roughness value is often undesirable, it can be difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase its manufacturing costs. This often results in a trade-off between the manufacturing cost of a component and its performance in application. Roughness can be measured by manual comparison against a "surface roughness comparator", a sample of known surface roughness, but more generally a surface profile measurement is made with a ''profilometer'' that can be contact (typically a diamond stylus) or optical (e.g. a white light interferometer). With widely application of CP Titanium grade -2, machining has become an important area which needs to be investigated in detail.

A well designed many set of experiments can be examined by using the L 27 orthogonal array (OA) experimental design with input factors like Pulse on Time, Pulse off Time , Peak Current(I_p), Flushing Pressure(W_p), Wire Feed Rate(W_f), Wire Tension(W_t), Servo Feed Rate(S_f) was considered for investigation .The effect of machining parameters on the response such as SR was investigated. In this research work, Taguchi analysis was used to find out the optimal level of the parameters.

Keywords
Wire electric discharge machining (WEDM), Titanium Grade- 2, Orthogonal array (OA), Taguchi analysis, Surface Roughness (SR).

I. Introduction

Wire-cutting EDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material and the wire electrode i.e. tool (wire) and workpiece material, separated by a thin film of dielectric fluid (Distilled water oil) that is continuously fed to the machining zone to flushing away the evaporated particles. WEDM was first introduced to the manufacturing industry in the late 1960s. The movement of wire is controlled numerically to achieve the desired 3D (3-dimensional) shape and accuracy of the work piece. In addition, the WEDM process is able to machine exotic and high strength and temperature resistive (HSTR) materials and eliminate the geometrical changes occurring in the machining of heat-treated steels. The high cost of both raw materials and processing limit their use to military applications, air craft, spacecraft, medical devices, connecting rods on expensive sports cars and some premium sports equipment and consumer electronics. Auto manufacturers Porsche and Ferrari also use titanium alloys in engine components due to its durable properties in these high stress engine environments. Although "commercially pure" titanium has acceptable mechanical properties and has been used for orthopedic and dental implants, after Computer Numerical Control (CNC) system was initiated into WEDM that brought about a recommended path and removes material from the work piece. WEDM uses electro-thermal mechanisms to cut electrically conductive materials. The material is removed by a continuous of sparks between the wire electrode and the work material in the presence of dielectric (distilled water), which creates a path for each discharge as the fluid becomes ionized in the gap between tool (wire) work material. The area where discharge takes place is heated to extremely high temperature, so that the surface is evaporated and removed. WEDM techniques have developed in many areas.

II. Experimental Details

A. Experimental Setup

All the experiments were carried out on the WEDM setup (Model: Electronica ELPULS 5S ultima 2f), the photograph which is shown in fig. 1.

Fig. 1: WEDM Setup

It mainly consists of Wire electrode, control unit, and dielectric circulation system. The machining takes place in the chamber while various process parameters are regulated through control units. Dielectric liquid is pumped through the reservoir where dielectric liquid flow rate can also be varied.

B. Selection of work piece, Tool Material and Dielectric Fluid

Workpiece of 80mm length, 80mm breadth and 5mm thickness of CP Titanium grade-2 was selected. The tool wire made up of brass with 0.25mm diameter was selected as anode. Dielectric fluid is a non-conductive liquid (deionized water) was taken as dielectric fluid for coolant medium of workpiece and tool wire during the cutting process.

C. Machining Parameters and Responses

The machining efficiency depends largely on machining parameters. So the judicious selection of parameters is of prime importance. From the literature review, the process parameters like Pulse on Time, Pulse off Time, Peak Current (I_p), Flushing Pressure (W_p), Wire Feed Rate(W_f), Wire Tension(W_t), Servo Feed Rate (S_f) were chosen for current experiment since they were found to have significant influences of Surface Roughness (SR).

The Surface Roughness (SR) can be defined as rate of irregularity of material from the workpiece. SR of Titanium grade-2 has been considered as the performances measure and was calculated by following formula:

$$\text{SR (Ra)} = \frac{Z1+Z2+Z3+\cdots Zn}{N}$$

- Z_1 - First Trial value of SR reading (Ra)
- Z_2 - Second Trial value of SR reading (Ra)
- Z_3 - Third Trial value of SR reading (Ra)
- N - Number of Trials

D. Design of Experiments

The experiments were planned as per three levels L27 Taguchi orthogonal array. The design was generated and analyzed by using MINITAB 17 statistical software. Seven factors at three levels were considered for the experimentation. The L27 orthogonal array (OA) for SR is represented by Table 1.

Table 1: Taguchi L27 Orthogonal Array for SR

Run no.	Pulse on Time (μsec)	Pulse off Time (μsec)	Peak Current (ampere)	Flushing Pressure (kg-pascal)	Wire Feed (m/min)	Wire Tension (kgf)	Servo Feed Rate (mm^3/min)	Trial- I (Ra)	Trial- II (Ra)	Trial- III (Ra)	Surface roughness(Ra) in (μm)
1	120	40	11	110	7	7	2150	2.46	2.86	2.40	R_a=2.57
2	120	40	11	110	8	8	2250	2.81	2.73	2.45	R_a=2.66
3	120	40	11	110	9	9	2350	2.56	2.65	2.79	R_a=2.66
4	120	50	12	120	7	7	2150	2.43	2.36	2.86	R_a=2.55
5	120	50	12	120	8	8	2250	2.54	3.03	2.87	R_a=2.81
6	120	50	12	120	9	9	2350	2.81	2.56	2.88	R_a=2.75
7	120	60	13	130	7	7	2150	2.65	2.08	2.51	R_a=2.41
8	120	60	13	130	8	8	2250	2.79	2.72	2.59	R_a=2.7
9	120	60	13	130	9	9	2350	2.74	2.95	2.44	R_a=2.71
10	122	40	12	130	7	8	2350	2.96	2.71	2.71	R_a=2.79
11	122	40	12	130	8	9	2150	2.81	2.49	2.68	R_a=2.66
12	122	40	12	130	9	7	2250	2.80	1.70	2.47	R_a=2.32
13	122	50	13	110	7	8	2350	2.54	2.72	2.77	R_a=2.67
14	122	50	13	110	8	9	2150	2.56	2.78	2.84	R_a=2.72
15	122	50	13	110	9	7	2250	2.88	2.39	2.46	R_a=2.57
16	122	60	11	120	7	8	2350	2.57	2.88	2.78	R_a=2.74
17	122	60	11	120	8	9	2150	2.55	2.34	2.55	R_a=2.48
18	122	60	11	120	9	7	2250	2.92	2.95	3.05	R_a=2.97
19	124	40	13	120	7	9	2250	2.72	2.90	3.01	R_a=2.87
20	124	40	13	120	8	7	2350	2.99	2.61	3.02	R_a=2.87
21	124	40	13	120	9	8	2150	3.26	2.97	3.29	R_a=3.17
22	124	50	11	130	7	9	2250	2.95	2.88	3.05	R_a=2.96
23	124	50	11	130	8	7	2350	3.03	2.38	2.60	R_a=2.67
24	124	50	11	130	9	8	2150	2.99	2.56	2.87	R_a=2.80
25	124	60	12	110	7	9	2250	3.08	2.90	3.07	R_a=3.01
26	124	60	12	110	8	7	2350	2.94	2.32	2.52	R_a=2.59
27	124	60	12	110	9	8	2150	2.84	1.98	2.27	R_a=2.36

III. Results and Discussion

A. Influence of Cutting Parameters on Responses Measured

Taguchi method is a statistical method developed by Taguchi and Konishi. Initially it was developed for improving the quality of goods manufactured (manufacturing process development), later its application was expanded to many other fields in Engineering, such as Biotechnology etc. Professional statisticians have acknowledged Taguchi's efforts especially in the development of designs for studying variation. Success in achieving the desired results involves a careful selection of process parameters and bifurcating them into control and noise factors. Selection of control factors must be made such that it nullifies the effect of noise factors. Taguchi Method involves identification of proper control factors to obtain the Optimum results of the process. Orthogonal Arrays (OA) are used to conduct a set of experiments. Results of these experiments are used to analyze the data and predict the quality of components produced.
Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results. The influence of different cutting parameters on different performance characteristics are explained in following sections:-

B. Main Effect Plot

The main effect plot displays the means for each group within a categorical variable. Minitab creates the main effects plot by plotting the means for each value of a categorical variable. A line connects the points for each variable, Look at the line to determine whether a main effect is present for a categorical variable, by disregarding the effect of any other input parameter present. The main effect plot of each response is explained below:-

C. Surface Roughness

Surface roughness is an important parameter influence on the performance of the machined components, further depending upon the type of contact, accuracy, friction and deformation and surface roughness measured by surface roughness tester. The productivity of WEDM can be determined through SR, so it is necessary to know the influence of the machining parameters on the SR during WEDM of CP Titanium Grade-2.

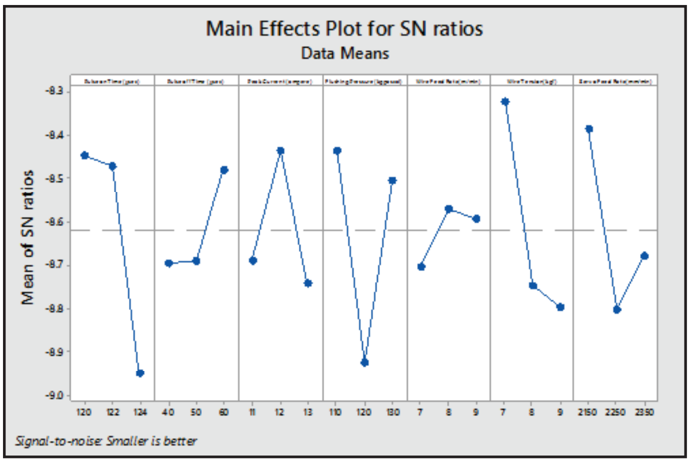

Fig. 2: Main Effect Plots for S/N ratios SR

During the process of Wire Electric Discharge Machining, the influence of various machining parameters like Pulse on Time, Pulse off Time, Peak Current(I_p), Flushing Pressure(W_p), Wire Feed Rate(W_f), Wire Tension(W_t), Servo Feed Rate(S_f) has significant effect on SR, as shown in main effect plot on S/N ratio of SR in fig. 2.

D. Analysis of Variance (ANOVA)

ANOVA is a collection of statistical models used to analyze the differences among group means and their associated procedures (such as "variation" among and between groups), developed by statistician and evolutionary biologist Ronald Fisher.ANOVA is based on comparing the variance (or variation) between the data samples to variation within each particular sample. Percentage of contribution of each factor can also be deducted from the ANOVA table.

Table 2: ANOVA for S/N Ratios (SR)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Pulse on Time (μsec)	2	0.15203	0.076015	1.94	0.186
Pulse off Time (μsec)	2	0.02392	0.011959	0.31	0.743
Peak Current (ampere)	2	0.04459	0.022293	0.57	0.581
Flushing Pressure(kg-pascal)	2	0.12667	0.063337	1.62	0.239
Wire Feed Rate(m/min)	2	0.00956	0.004781	0.12	0.886
Wire Tension(kgf)	2	0.11470	0.057348	1.46	0.270
Servo Feed Rate(mm^3/min)	2	0.07525	0.037626	0.96	0.410
Error	12	0.47016	0.039180		
Total	26	1.01687			

E. Response Table for Outputs

Response table also indicate which process parameters has greater influence on the responses measured by giving the process parameter a rank. Also one can infer the optimal condition from the response table. The lowest value corresponding to the particular level in the response table is the optimal one for the SR.

Table 3: Response Table for S/N Ratios Smaller is Better (SR)

Level	Pulse on Time (μsec)	Pulse off Time (μsec)	Peak Current (ampere)	Flushing Pressure (kgpascal)	Wire Feed Rate (m/min)	Wire Tension (kgf)	Servo Feed Rate (mm^3/ min)
1	-8.446	**-8.694**	-8.688	-8.434	**-8.702**	-8.321	-8.386
2	-8.471	-8.690	-8.434	**-8.925**	-8.570	-8.747	**-8.802**
3	**-8.948**	-8.480	**-8.743**	-8.505	-8.592	**-8.797**	-8.677
Delta	0.502	0.214	0.309	0.491	0.132	0.477	0.416
Rank	1	6	5	2	7	3	4

From the response table of SR (Table 3) it can be also inferred that the pulse on time.

VI. Conclusions

1. None of the process parameters was found to have a significant effect on SR of the Specimen material.
2. The following combination gives the setting of optimal level of the process parameters, which was found in the trial no. 19. In the L27 orthogonal array in Table no 4.

Table 4: Optimal combination

Run no.	Pulse on Time (μsec)	Pulse off Time (μsec)	Peak Current (ampere)	Flushing Pressure (kg-pascal)	Wire Feed (m/min)	Wire Tension (kgf)	Servo Feed Rate (mm3/min)
1.	124	40	13	120	7	9	2250

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