Study of controlling parameters during electro-discharge machining of titanium alloy using grey relation analysis coupled with Taguchi philosophy

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Abstract. Titanium grade 4 is a widely used material in the manufacturing industry due to its properties like high strength to weight ratio, low density, high-temperature resistivity, high corrosiveness. But due to its high strength, it is hard to machine in conventional machines. So here a different approach is shown to machine Titanium. Electro-discharge machine(EDM) is used for machining this metal. In this research work, an investigation is done to find the set of process parameters (peak current, gap voltage, pulse on time) for which responses like metal removal rate will be highest, but electrode wear rate and surface roughness is least. Optimization is done using Grey relation analysis coupled with Taguchi philosophy.

Keywords: Electro Discharge Machining, Titanium grade-4, copper tool, Grey Relation Analysis, Taguchi method.

1. Introduction

Electro-discharge machining (EDM) is a broadly used non-conventional machining method. The main benefit of using EDM is that it works on electric spark generation and metal erosion technology. That’s why it can machine hard materials easily. Here EDM is used for machining of titanium metal. Titanium Grade-4 is a tough material with very less weight, high corrosion resistant, high-temperature resistant, and non-toxic. That’s why it is used in different fields like aerospace industry, power plants, medical operations for making spacecraft, missiles, airplane parts, naval ships, armor plating, pipes of power plants, human body parts, etc. But it is quite hard to machine by conventional machining method. That’s why EDM is used in this study. During EDM machining we have taken peak current, gap voltage and pulse on time as input parameters and an investigation are done to find the optimum values of input parameters for which material removal rate (MRR) will be high, but electrode wear rate (EWR) and surface roughness (SR) will be low.

Jatti [1] have studied the outcome of different parameters on responses like MRR and TWR during EDM machining of NiTi alloy and Ni Cu alloy. He used Utility method coupled with Taguchi philosophy for optimization. He observed that the peak current is the most significant factor among all the parameters. Rouniyar et al. [2] experimented the effects of controlling parameters on various responses during powder mixed EDM machining of Titanium alloy using grey relation analysis. He found that discharge current has the highest impact on responses (i.e., MRR and SR). Johan et.al.[3] has presented an experimental study to find the surface integrity of nickel-based alloy, Inconel 718 through Electro Discharge Machine(EDM) and also studied the fatigue performance of this hard
material. Manohar et al. [4] studied to print metallic parts using laser powder bed fusion from hard alloy like Inconel 718 and also investigate the milling behavior of this hard material. Kumar et al. [5] have done an experimental study to find temperature profile, Material Removal Rate (MRR). Material Removal is also calculated on multi-discharge machining by calculating a number of a pulse. Kliuev et.al.[6] has presented an experimental study which describes a large setup for high-speed imaging of Electro Discharge Machine drilling process with an electrode and also with multi-hole flushing. Tripathi et.al.[7] has done a research work which studies the output responses of machining nickel-based alloy, Inconel 718 like Material Removal Rate(MRR), Tool wear rate(TWR) and Surface Roughness. Klocke et.al.[8] has presented an experimental study that studied technological evaluation and machining technologies for the production of fir tree slots by EDM process by using hard material alloy. Devendranath et.al.[9] has done an experimental study to determine the optimal process parameters of CO2 laser welding after iteration with different velocity for Nickel-based superalloy, Inconel 718. Yong et al. [10] have presented an experimental study to investigate the output performance like Material Removal rate(MRR), low electrode wear and small working gap by Grey-Taguchi method of a nickel-based alloy, Inconel 718. Geethapriyan et.al.[11] has presented an experimental study to drill the nickel-based superalloy, Inconel 718 through Electro Discharge machining processes. Qu et al. [12] studied in which the brazed diamond wheel was employed on the alloy to substitute an electrodeposited diamond wheel. Rahul et al. [13] also experimented the optimization of parameters on Inconel 601, 625, 718 and 825 super alloy through electro-discharge machine based on 5 factors 4 levels L16 orthogonal array and calculated the optimum results using the Topsis and Taguchi method for it. Rahul et al. [14] experimentally investigated machinability aspects of machining of Inconel 718 with a copper tool. They conducted the research work based on L25 OA by taking various parameters such as Vg, Ip, Ton, τ and Flush pressure and taken various responses such as Tool Wear Rate (TWR), Surface Roughness (Ra), Surface Crack Density (SCD) and White Layer Thickness (WLT).

The primary aim of this research work is to study the output responses like MRR, TWR, SR on a Titanium grade-4 using Electro Discharge Machine (EDM) by giving input process parameters like Peak Current(IP), Open Voltage (Vg), Pulse-On-Time (Ton).

2. Experimentation

Titanium grade 4 (3.7065, R50700) round workpiece is used as work material, and the diameter of the work material is 15mm. The chemical formation (wt%) of titanium grade-4 is shown in Table.1. Copper rod of the round cross-area with a diameter as 10 mm has been utilized as an electrode (Fig. 2). The investigations have been completed on die-sinking EDM (Make: Smart ZNC, Electronica Machine Tools Ltd, Pune, India) setup (Fig. 3). 125cc SAE-40 grade oil is utilized as a dielectric liquid. The viscosity of EDM oil is 2.16 cs at 38°C. The workpiece is kept as positive. Analysis has been done utilizing three controllable process parameters (gap voltage, peak current, pulse-on time) each fluctuated at three distinct levels (Table. 2). The structure of analysis has been arranged according to 3-factor-3-level L 9 Orthogonal Array (OA). The machining term for each test run has been kept fixed (30 minutes). The machining reactions viz. Average roughness(Ra), Metal Removal Rate(MRR), and Tool Wear Rate(TWR) have been measured for each trial run. The depiction of EDMed titanium grade-4 has been furnished in (Fig. 1). For all the experiments flushing fluid pressure is taken as 8 kg/cm².

| Elements   | Carbon | Iron | Hydrogen | Nitrogen | Oxygen | Titanium |
|------------|--------|------|----------|----------|--------|----------|
| Weight %   | 0.1    | 0.5  | 0.015    | 0.05     | 0.335  | 99       |
3. Methodology

3.1 Grey Relation Analysis

Grey relational analysis (GRA) was developed by Julong Deng. It is one of the most widely used methods of Grey system theory. In this investigation, the input parameters are converted into a standard range in a scale range of 0 and 1. The response parameter MRR is Larger the better type, and TWR and SR is Smaller the better type. The Normalized value is $x_i^*$. 

Step1: Calculation of normalized value.

The Normalized value for MRR is written as

$$x_i^* = \frac{x_i - x_{\text{min}}}{x_{\text{max}} - x_{\text{min}}}$$

and for TWR and SR the normalized value is written as

$$x_i^* = \frac{x_{\text{max}} - x_i}{x_{\text{max}} - x_{\text{min}}}$$

Here, $i = \text{Experiment number i.e. 1, 2, 3}$; $x_i = \text{standardized value of MRR, TWR, and SR for } i^{\text{th}} \text{ experiment number.}$ $x_{\text{min}} = \text{Minimum value of MRR, TWR, and SR among the 9 experiments.}$ $x_{\text{max}} = \text{Maximum value among the 9 experiments.}$

Step 2: Evaluate Deviation Sequences ($\Delta$) for the normalized data.

After the standardization method, all the performance value like MRR, TW, and SR will be scaled into $[0,1]$. The main objective of deviation arrangement is to find out the alternative whose standardized values is closest to the reference value. We have to calculate the deviation sequence with the help of normalized values of performance parameters for each experiment.

Deviation sequence $\Delta_i = 1$- the Normalized value of performance parameter for up to $i^{\text{th}}$ experiment. Here $I = \text{experiment number, i.e. 1, 2...9.}$

Step 3: Calculation for Grey Relation coefficient (GRC) and Grey Relational Grade (GRG).

The GRC is expressed as

$$\text{GRC} = \frac{d_{\text{min}} - f_{\text{max}}}{d_{ij} + f_{\text{max}}}$$

Here $i = \text{experiment number and } j = \text{response parameter. } d_{\text{min}} = \text{minimum values of deviation for } j^{\text{th}} \text{ response parameter among all the 9 experiments, } d_{\text{max}} = \text{maximum values of deviation for } j^{\text{th}} \text{ Response parameter among all the 9 experiments. } \Gamma = \text{distinguishing factor and the value is taken as 0.5.}$ After finding the value of GRC for all 9 experiments for all performance parameter, GRG was calculated for every experiment.
The GRG is expressed as,
\[ GRG_i = (W_g \times GRG_{\text{MRR}i}) + (W_g \times GRG_{\text{TWR}i}) + (W_g \times GRG_{\text{Ra}i}) \]
Here, \( i \) = Experiment number, \( W_g \) = weightage of response parameter = 0.33

4. Data analysis
At first, from experimental data’s of MRR, SR, and TWR, we calculated the derivation sequence of each response. Then we calculated the grey relation coefficient for each response. Then the grey relation grade (GRG) is found out and used it for S/N ratio calculation (Table.3). Then response table for means is found out on Minitab software (Table.4). Figure.4 shows the graph of mean effects for S/N ratios.

| Exp. No. | \( \Delta_{\text{MRR}} \) | \( \Delta_{\text{TWR}} \) | \( \Delta_{\text{Ra}} \) | GRG_{\text{CMRR}} | GRG_{\text{CTWR}} | GRG_{\text{CSR}} | GRG | S/N Ratio | Predicted Value |
|---------|----------------|----------------|----------------|-----------------|-----------------|----------------|-----|-----------|----------------|
| 1       | 0.044          | 0.99           | 1.00           | 0.91            | 0.333           | 0.333          | 0.523| 0.523     |                |
|         | 0.063          | 1.00           | 0.82           | 0.88            | 0.333           | 0.376          | 0.527| 0.527     |                |
|         | 0.000          | 0.96           | 0.69           | 1.00            | 0.340           | 0.417          | 0.580| 0.580     |                |
|         | 0.404          | 0.94           | 0.69           | 0.55            | 0.345           | 0.417          | 0.434| 0.434     |                |
|         | 0.550          | 0.00           | 0.58           | 0.47            | 1.000           | 0.458          | 0.638| 0.608     | 0.61 653       |
|         | 0.603          | 0.83           | 0.31           | 0.45            | 0.373           | 0.615          | 0.476| 0.476     |                |
|         | 0.529          | 0.94           | 0.56           | 0.48            | 0.344           | 0.469          | 0.428| 0.428     |                |
|         | 0.813          | 0.93           | 0.06           | 0.38            | 0.347           | 0.892          | 0.534| 0.534     |                |
|         | 1.000          | 0.99           | 0.00           | 0.33            | 0.333           | 1.000          | 0.550| 0.550     |                |
5. Conclusion

From the above research work, we concluded the points that are given below.

- The Grey relation analysis integrated with the Taguchi approach utilized here to find a set of controlling parameters such as gap voltage, peak current, pulse-on-time to get high MRR but with low TWR and SR simultaneously.
- The optimum controlling parameters found out as (A₁B₂C₃), i.e. \( I_p=20A \), \( T_{on}=305\mu s \), and \( V_g=77V \).
- Mean response table (mean S/N ratio of GRG) shows that pulse on time (T on) has the highest significance on influencing the machining performances.

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