Optimization of process parameters in Electric Discharge Machining Process of Ti-6Al-4V alloy using hybrid Taguchi based MOORA method

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Abstract. Electric Discharge Machining (EDM) process is used where the materials are difficult to machine by conventional methods. Titanium alloy is extensively used in aerospace industries because of its light weight and strength. This titanium alloy can be grouped into hard to cut materials and EDM is preferred for machining. In this work, an attempt is made by machinability analysis of titanium alloy on EDM using non-treated, cryogenically treated and tempered condition copper electrodes. The input parameters chosen are current, pulse on time, pulse off time and electrodes with different conditions. The output parameters are investigated include Material Removal Rate (MRR) and Tool Wear Rate (TWR). Taguchi based Multi Objective Optimization Ratio Analysis (MOORA) is used to find value of optimum input and output parameters. The result showed that cryogenically treated with tempered copper electrodes are good in machining performance and proposed Taguchi bases MOORA method has capable of solving multiple objectives simultaneously.

1. Introduction

In EDM process, lesser wear of the electrode with higher removal of material plays major role which influence the productivity, geometrical dimensions, electrode cost and electrode shape is not reproduced on the work piece. Cryogenic treatment of electrode is employed to optimize the properties of material like resistance to wear, reduction in residual stress, refinement of the fine grain size, good electrical characteristics, toughness and the cryogenic treatment is eco-friendly approach [1].

Taguchi approach is a standard tool of optimization [2]. But, it can be used for single objective optimization effectively. Hence Taguchi method is couple with grey analysis, desirability analysis and utility concept. Recently, Multi Criteria Decision Making (MCDM) concept is utilized for manufacturing environment for process parameters optimization [3, 4]. It is a widely used statistical approach for finding the best alternatives from the various other alternatives available for the decision making requirements. MCDM approach is also used for solving the problems of multi objective optimization which attempts to optimize more than two objectives simultaneously. MOORA is a MCDM concept used by authors to obtain optimum values of parameters in the work from the alternatives for the multiple objective problems. The concept is to identify the optimum solution that is near to the positive ideal solution and far from the worst solution. In this approach both factors like intangible and tangible are investigated in a organized manner to generate near optimal solution to multiple criteria problems [5].
2. Literature Review

Abdul Kareem et al. [6] conducted experiments and analyzed the effect of cryogenic cooled copper electrode on titanium alloy in EDM. In their work, process parameters such as current, voltage, pulse on time and pulse off time studied and for the response parameters like MRR, TWR and surface finish. The outcome showed that electrode wear was decreased by 27% approximately with liquid nitrogen cooled electrode. Srivastava and Pandey [7] study shows that the performance of liquid nitrogen cooled electrode for machining of M2 grade steel by EDM. The various outcomes concluded that there was a reduction of electrodes wear by 20% and surface roughness improvement by 27% with cryogenic cooled electrode. Kumar et al. [8] has analyzed the performance of the tool which was cryogenically treated and result showed that reduction of electrode wear and the ability to machine 718 Inconel in a powder mixed EDM. EDM process along with electrode which is cryogenically treated and its effects is studied by Murali et al. [9] and shows material removal varies significantly by the use of treated electrodes.

Sahu [10] used MOORA method for process optimization in EDM process. Work piece used as stainless steel and electrode used as AlSiMg electrode. Electrodes were prepared by additive manufacturing technique. The result revealed that electrode was performed better. MOORA method was used successfully for process parameter optimization. Liang et al. [11] used MOORA based Taguchi method for optimizing the parameters in welding process. The tests were planned as per the Taguchi orthogonal array. Signal to noise ratio was estimated then MOORA method was successfully employed. The result revealed that MOORA based Taguchi method had capable of solving multi objective problems. Singaravel et al [12] optimized process parameters using Taguchi based VIKOR method in EDM process. In their work, a dielectric fluid vegetable oil is used and electrode was tempered and cryogenically treated. The outcome revealed that the vegetable oil used as dielectric leads to sustainability in manufacturing and Taguchi based VIKOR method given enhanced process parameters.

3. Experimental Procedure

Die-sinking EDM machine is utilized to conduct the experiments. Figure 1 shows the machining zone of EDM process. In the following work, Titanium based alloy (Ti- 6Al-4V) is considered as work piece material which is used for aerospace industries and this material is treated as a difficult to machine [13]. Copper is widely used electrode materials and these electrodes are cryogenically treated and tempered before they are used in machining. Process parameters are pulse off time, pulse on time, voltage and current. Selected input parameters in this work and their levels are given in Table 1, based on few initial tests and literature study these parameters are selected. Output parameters considered are MRR and TWR. Experiments are conducted as per Taguchi L9 Orthogonal array [14]. The depth of cut for all experiments is kept constant at 1.0 mm and diameter of the electrode is 6 mm. Table 2 shows the results of the experiments that are conducted in EDM on titanium alloy. Figure 2 shows the machined samples.

Table 1. Process parameters and their levels

| Parameters          | Level 1         | Level 2               | Level 3          |
|---------------------|-----------------|-----------------------|------------------|
|                     | Treated (T)     | Treated &Tempered (TT)| Cryogenic treated (NT) |
| Electrode           |                 |                       |                  |
| Current (Amps)      | 4               | 6                     | 8                |
| Pulse off time (µs) | 300             | 400                   | 500              |
| Pulse on time (µs)  | 500             | 600                   | 700              |
Table 2. Experimental results of EDM process on titanium alloy.

| Ex. No | Electrode conditions | Current in Amps | Pulse on time in µs | Pulse off time in µs | MRR in mm³/min | TWR in mm³/min |
|--------|----------------------|-----------------|---------------------|---------------------|----------------|----------------|
| 1      | T                    | 4               | 500                 | 300                 | 0.2073         | 0.067          |
| 2      | T                    | 6               | 600                 | 400                 | 0.5599         | 0.058          |
| 3      | T                    | 8               | 700                 | 500                 | 0.1694         | 0.087          |
| 4      | TT                   | 4               | 600                 | 500                 | 0.3388         | 0.016          |
| 5      | TT                   | 6               | 700                 | 300                 | 0.6246         | 0.017          |
| 6      | TT                   | 8               | 500                 | 400                 | 0.2976         | 0.061          |
| 7      | NT                   | 4               | 700                 | 400                 | 0.1710         | 0.044          |
| 8      | NT                   | 6               | 500                 | 500                 | 0.4033         | 0.064          |
| 9      | NT                   | 8               | 600                 | 300                 | 0.7551         | 0.162          |

Electrodes and work piece weight differences are considered before and after machining process, which are measured by using a weighing machine and the following equation (1) has been used to determine MRR and equation (2) has been used to determine TWR [15, 16]

\[
MRR = \frac{(W_{wbm} - W_{wam})}{t \times \rho_w} \text{ mm}^3/\text{min} \quad (1)
\]

\[
TWR = \frac{(W_{ebm} - W_{eam})}{t \times \rho_e} \text{ mm}^3/\text{min} \quad (2)
\]

Where, \( W_{wbm} \) = work piece weight before starting of machining (g), \( W_{wam} \) = work piece weight after completion of machining (g), \( W_{ebm} \) = Electrode weight before starting of machining, \( W_{eam} \) = Electrode weight after completion of machining, \( t \) = Machining time (min), \( \rho_w \) = Work piece Density (g/cm³), \( \rho_e \) = Electrode material (g/cm³).
Cryogenic treatment and followed by tempering are conducted on selected copper electrodes. Cryogenic word indicates very low temperature and in this work -196 ºC is used and 150º C is used for tempering cycle [1]. Figure 3 shows tempering and Cryogenic cycle of copper (Cu) electrodes.

**Figure 3.** Tempering and Cryogenic cycle of Cu electrodes

### 4. Methodology

MOORA method is a kind of MCDM strategy which has capacity to tackle multi measures target issues. MOORA method is viewed as amplification (valuable) and minimization (non-useful) options for expectation of ideal other options and furthermore disposes of unsatisfactory other options. The accompanying strategies are utilized for MOORA technique [10, 11 and 17].

- Representation of problem statement and formation of objective function
- Development of decision matrix.
- Normalization of input data.
5. Results and Discussion

In the present investigation, output parameters are MRR and TWR. Table 2 contains the experimental results. MOORA analysis determines the optimal solution by considering non beneficial and beneficial objectives. This analysis has simple mathematical problems and does not require complicated software’s to execute. Depending on different high values of normalized assessment the optimum and better conditions of machining obtained are current of 8 Amps, pulse off time 400 µs and pulse on time 500 µs with tempered and treated electrodes. MOORA approach uses simple ratio analysis and easy to execute compared to other statistical analysis approach. Hence, this proposed method is highly desirable for solving multiple objective problems [17].

It is observed from the experiments, an increase of pulse on time leads to wider discharge channel and spark energy was available for longer period of time. Hence, evaporating and melting was more and MRR is high. Lower pulse off time influences higher energy transfer per unit time. Lower pulse off time leads higher plasma discharge channel and hence increases the area for striking the positive ions on the work piece. Whenever pulse on time increases to a certain value there is positive ions strike on the surface of electrode for a prolonged duration. Due to this reason many researchers have reported that there is an increase in TWR [18]. In this work, cryogenically treated and tempered electrodes are given good performance than other electrodes. This is because of very hard & brittle carbide compound formation on electrodes surface, fine grain refinement, due to this thermal & wear resistive property characteristics are better compared to non-treated tools. Due to the above reason
increased MRR less TWR are observed and similar types of observation are reported by Kumar et al. [7].

6. Conclusions

- Taguchi based MOORA method is the most versatile technique to determine optimum process parameters and normalized assessment value utilized to determine optimum parameters. The alternative of input and output parameters are sort out based on their normalized assessment values.
- Parameters which are optimized here are current of 8 Amps, pulse off time of 400 µs, pulse on time of 500 µs with cryogenically treated and tempered tool respectively.
- The properties electrodes is enhanced by Cryogenic treatment. Increased MRR and reduced TWR are found by cryogenically treated electrode in EDM process.
- For efficient optimization of turning, the statistic & experimental approach were very useful. This analysis could be utilized to optimizing and improving the process parameters. Also this analysis could be extended for the study of other different machining techniques of manufacturing.

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