Experimental investigation on powder mixed electro-discharge machining (EDM) of D2 die steel with De-ionized water as dielectric medium

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Abstract. In this work, z-axis controlled electro-discharge machine is used to machine D2 die steel. Tungsten powder is used as powder in dielectric medium in order to boost the material removal rate (MRR) in powder mixed electro-discharge machining (PMEDM). Input characteristics used in this process are applied current, pulse on time and pulse off time. The influence of tungsten powders in dielectric medium is studied and the result shows that there is significant improvement in the MRR as the main objective is to boost MRR. Taguchi techniques are carried out to optimize the input characteristics and ANOVA table is used to describe the individual performance of the process parameters. The optimal conditions obtained are validated with the confirmation experiments.

Keywords: Powder mixed Electro-Discharge Machining, Optimization, Process parameters, Taguchi technique, Tungsten powder, ANOVA

1. Introduction

Electro-discharge machining (EDM) has been considered as the best method and widely employed in die manufacturing industries, as the accuracy and precision obtained by this method is highly appreciable and even the difficult to cut materials can be machined. The main principle behind this thermo-electrical process is that, the undesired material removal takes place without any physical contact between the tool and the work piece, as the spark generated in the inter-electrode gap (IEG) induces mechanical stress and this helps in removing the material. The applied current to the concentrated area should be in a controlled manner as this helps in obtaining the desired material with proper surface finish. The input parameters have to be properly chosen as this should reduce the tooling and the operating cost.

Rajyalakshmi et al [1] have optimized the process parameters using fuzzy grey-relational analysis (FGRA) in wire cut electro-discharge machining (WEDM) such as flushing pressure, servo voltage, wire feed, wire tension etc., to obtain better output parameters such as material removal rate (MRR) and...
surface roughness ($R_a$) using $L_{36}$ orthogonal array (OA) in Inconel 825 alloy and they have concluded that the pulse on time ($T_{on}$) and pulse off time ($T_{off}$) plays a significant role in affecting the output parameters. Vijaya Rammath et al [2] have done experiments on electro-discharge machining (EDM) to maximize the material removal rate (MRR) and have optimized the experimental results using Taguchi technique by varying the input parameters and have concluded that pulse on time plays a significant role in affecting the MRR as for more time the material has been exposed to current as well as the electrolyte more MRR occurs. Jeykrishnan et al [3] have done many trial experiments on EDM using EN - 24 tool steel by altering several input parameters such as $T_{on}$, $T_{off}$ and applied current and have obtained the best characteristics such as MRR, $R_a$ and tool wear rate (TWR) using Taguchi techniques. Das et al [4] have performed drilling operations and have measured the cutting forces by altering the input parameters and optimized the output parameters using artificial neural network (ANN) and they have concluded that when the diameter of the drill bit increases, the parameters such as thrust force, torque etc. also increases. Saha et al [5] have performed milling operation on aluminium metal matrix composite (MMC) which is reinforced with copper and titanium particles and performed several trials using Taguchi’s $L_{25}$ OA and have varied optimized the results using grey fuzzy logic and have reported that the cutting speed affects the output parameters more followed by feed rate and the depth of cut. Singh et al [6] have done experiments on aluminium MMCs by varying its parameters like speed, feed and step diameter to optimize the characteristics such as thrust force, $R_a$ etc. using grey relational analysis and have concluded that the speed has been the most significant parameters in obtaining the better results. Krisnanto et al [7] have performed experiments on Kevlar fibers by optimizing the parameters such as speed, feed and tool geometries in angles using Taguchi-grey-fuzzy method and obtained the best characteristics such as thrust force, $R_a$ etc. using grey relational analysis and have concluded that the speed has been the most significant parameters in obtaining the better results. Shebin et al [8] have performed experiments on EDM by using powder mixed dielectric medium while machining steels and have reported that the characteristics such as MRR, TWR has sufficiently increases after the addition of powders in the dielectric and have optimized the input parameters to get better output using Taguchi technique. They have concluded that the applied current has more impact on the responses such as MRR, $R_a$, tool wear rate (TWR) followed by the voltage and the electrolyte concentration and have optimized the results using Taguchi technique. They have concluded that the applied current has more impact on the responses such as MRR, $R_a$, tool wear rate (TWR) followed by the voltage and the electrolyte concentration and has been significant that when the material receives more current, the MRR will be more. RaghuRaman et al [11] have done experiments based on Taguchi’s $L_9$ OA on EDM while machining mild steel and have optimized the characteristics using grey relational analysis (GRA) and have concluded that the applied current has more impact on the output characteristics. Pai et al [12] have optimized the output characteristics such as MRR, TWR, radial overcut (ROC), $R_a$ using GRA while machining aluminium MMCs in EDM process and they have concluded that pulse on time plays an important role in getting the best output parameters. Jeykrishnan et al [13 and 14] performed machining operations based on Taguchi technique’s OA in Inconel 825 alloy in EDM by altering the input characteristics in obtaining the best response such as $R_a$ and have reported that the pulse on time and the discharge current plays a significant role in increasing the surface finish.

The main objective of this work is to obtain maximum MRR in machining D2 die steels by employing Tungsten powder in de-ionized water as the dielectric medium and also the effect of process parameters such as current, $T_{on}$ and $T_{off}$. 

2. Experimental details

2.1 Experimental setup

The machining has been carried out on V5030 GRACE EDM machine. AISI D2 die steel has been chosen as the work piece material with hardness of 57 HRC and has a density of 7850 kg/m³ and the chemical composition has been given in table 1. The work piece has been ground before starting the machining. Copper has been chosen as the electrode. The machining has been done with positive polarity. The input parameters chosen for machining were applied current (A), T\(_{\text{on}}\) (µs) and T\(_{\text{off}}\) (µs). De-ionized water has been chosen as the dielectric medium by adding tungsten powder as this improves the MRR significantly. The IEG and the feed rate of the tool have been kept constant throughout the machining process.

Table 1. Composition of AISI D2 Die Steel

| C   | Si  | Cr   | Mo  | V   | Fe  |
|-----|-----|------|-----|-----|-----|
| 1.50| 0.30| 12.00| 0.80| 0.90| Bal |

2.2 Selection of machining parameters

In this work, the three parameters chosen were the applied current, T\(_{\text{on}}\) and T\(_{\text{off}}\) and the other characteristics such as IEG, feed rate, machining time have been kept constant. The levels chosen for the variables have been given in table 2.

Table 2. Variables with their levels

| Parameters/Levels     | I  | II | III |
|-----------------------|----|----|-----|
| Current (A)           | 6  | 10 | 14  |
| Pulse on time (µs)    | 6  | 8  | 10  |
| Pulse off time (µs)   | 6  | 7  | 8   |

3. Results and discussions

Taguchi technique has been chosen as the optimization technique with L9 orthogonal array (OA) and “Larger the better” option has been chosen as the output parameter MRR has to be maximized during the machining operation and the formula for obtaining the signal to noise (S/N) ratio has been given in eqn 1. AISI D2 die steel has been machined according to the trials given by L9 OA using copper as a tool electrode in a dielectric medium of de-ionized water mixed with tungsten powder.

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S/N \text{ ratio (MRR)} = -10 \log \left[ \text{sum} \left( \frac{1}{Y^2} \right) / n \right]
\] (1)
The S/N ratio for MRR has been obtained through MINITAB software [15] and it has been given in table 3.

Table 3. Experimental output

| Exp. No | Input Variables | Output Variables |
|---------|-----------------|------------------|
|         | Current (A)  | Pulse on time (µs) | Pulse off time (µs) | MRR | S/N ratio for MRR |
| 1       | 6              | 6                  | 6                  | 0.0219 | -33.1911 |
| 2       | 6              | 8                  | 7                  | 0.0226 | -32.9178 |
| 3       | 6              | 10                 | 8                  | 0.0254 | -31.9033 |
| 4       | 10             | 6                  | 7                  | 0.0211 | -33.5144 |
| 5       | 10             | 8                  | 8                  | 0.0218 | -33.2309 |
| 6       | 10             | 10                 | 6                  | 0.0226 | -32.9178 |
| **7**   | **14**         | **6**              | **8**              | **0.0315** | **-30.0338** |
| 8       | 14             | 8                  | 6                  | 0.0242 | -32.3237 |
| 9       | 14             | 10                 | 7                  | 0.0298 | -30.5157 |

3.1 Effect of input parameters on MRR in AISI D2 Die steel

The maximum MRR occurs with the highest applied current and pulse off time and lowest pulse on time as this has been shown in figure 1. MRR increases when the applied current increases because of the occurrence of more spark and also the amount of supplied energy to the work piece will be more which results in the removal of undesired work piece material. Also, the MRR increases when the pulse off time increases, due to the presence of arcing as well as the gathered pressure drops at once, thereby giving enough time for the material to get removed and also the material finds enough time to get flushed by the dielectric medium. But, MRR fluctuates upon varying the pulse on time as more material gets melted or vaporized with high pulse on time, however the debris particles didn’t have adequate flushing time to get cleared in the inter – electrode gap (IEG) between the tool and the work piece. The response table for S/N ratio has been given in table 4, which indicates that the applied current has the most influence on affecting the MRR, followed by $T_{on}$ and $T_{off}$. 
Figure 1. S/N ratio graph for MRR

Table 4. Response table for S/N ratio of MRR

| Levels/Parameters | Current | Pulse on time | Pulse off time |
|-------------------|---------|---------------|----------------|
| 1                 | -32.67  | -32.25        | -32.81         |
| 2                 | -33.22  | -32.82        | -32.32         |
| 3                 | -30.96  | -31.71        | -31.72         |
| (Max-Min)         | 2.26    | 1.11          | 1.09           |
| Rank              | 1       | 2             | 3              |

3.2 ANOVA Table

Analysis of Variance (ANOVA) table is nothing but a statistical tool, which indicates the individual parameter contribution towards the output parameter. The ANOVA table has been calculated and has been given in table 5. It has been inferred from the ANOVA table that, applied current has been the most significant parameter as it has more F-value and it has been followed by pulse on time and pulse off time, as more F-value determines the most significant parameter. The results have been confirmed with 95% confidence level and the co-efficient of determination (i.e.) $R^2$ for the table has been 0.948. It indicates how far the factor or the parameters affects the output characteristics.
Table 5. ANOVA table

| Source       | DoF | Adj SS   | Adj MS   | F-value | P-value |
|--------------|-----|----------|----------|---------|---------|
| Current      | 2   | 0.000074 | 0.000037 | 12.25   | 0.075   |
| Pulse on time| 2   | 0.000017 | 0.000008 | 2.78    | 0.265   |
| Pulse off time| 2  | 0.000014 | 0.000007 | 2.41    | 0.293   |
| Error        | 2   | 0.000006 | 0.000003 | ---     | ---     |
| Total        | 8   | 0.000111 | ---      | ---     | ---     |

Table has been done with 95% confidence level and \( R^2 = 0.948 \)

4. Conclusion

Thus the present work has the effect of machining AISI D2 die steel in EDM by using different input variables such as applied current, \( T_{on} \) and \( T_{off} \) and these parameters have been optimized to obtain best MRR.

- The optimal results obtained using Taguchi technique for maximized MRR were applied current with 14A, pulse on time with 10\( \mu \)s and pulse off time with 8\( \mu \)s.
- The percentage contribution of each parameters have also been found using ANOVA table and it suggests, the applied current has the most significance in affecting the MRR in machining AISI D2 die steel using EDM followed by the pulse on time and pulse off time.

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