NSGA OPTIMIZATION OF PERFORMANCE OF EDM USING POWDER MIXED DISTILLED WATER DIELECTRIC FLUID

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ABSTRACT
Powder mixed electrical discharge machining is one of the techniques used in EDM to improve the machining characteristics. In this work aluminium powder-mixed distilled water used as dielectric fluid. Pulse peak current, pulse on-time and concentration of aluminium powder are varied to optimize the machining of W300 die-steel. The experiments are planned using face centered central composite design to find the optimal machining parameters to obtain high material removal rate (MRR) and low surface roughness (Ra). Empirical models are developed for MRR and Ra, using response surface methodology (RSM) to study the effect of process parameter. Using non-dominated sorting genetic algorithms (NSGA-II) the optimal process parameters for achieving maximum MRR and minimum possible surface roughness is obtained and reported here.

Keywords: MRR, NSGA, Powder-Mixed EDM, Ra.

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1. INTRODUCTION
Dielectric fluids fulfil an important function to maximizing quality and reduce the cost. It is imperative for the manufacturing industries to be concerned with minimizing environmental impact. To achieve this, research is continuously being done improve the process efficiency by alternative dielectric fluids.

Studies during the EDM of SK4 die steel, it is found that organic compound mixed dielectric fluid found to improve the performance[1]. These are 10%, 25%, and 50%
concentrations of glycerine, glycol, dextrose, and sucrose solution in water. It was reported that machining characteristics of polyethylene glycols are competitive with conventional EDM oil. More over MMR increased with increase in the concentration and with increase in the molecular weight.

During machining of 56NiCrMoV7[2], it is found that high concentrated solution of glycerine has advantage over hydrocarbon oils during rough machining. Glycerine solution yields high material removal rate, low tool wear and slightly improved surface roughness values as compared to Shell K-60 hydrocarbon dielectric. In a similar study using urea solution found to form TiN hard layer due to element transfer during machining of Ti alloy [3].

In addition to the organic compounds, SiC powder[4] and B₄C powder mixed with water were investigated during the machining of Ti-6Al-4V alloy. B₄C mixed water found to reduce TWR, improved the surface quality and reduced the WLT when compared to pure water.

The stochastic nature of discharge mechanisms of PM EDM influenced by many process parameters makes analytical modeling of the process difficult. Various researchers made an attempt to develop semi-empirical models by response surface methodology (RSM) [5], finite element analysis (FEA)[6] and fuzzy logic analysis coupled with Taguchi dynamic approach[7]. In several cases, signal to noise ratio (S/N) and analysis of variance (ANOVA) techniques are used to identify the most influencing process parameters and to find the amount of deviation from the desired performance. Empirical model developed while machining Ti-6246 work piece with SiC mixed fluid, show that surface roughness was highly influenced by the presence of SiC additives [8].

2. EXPERIMENTATION
The experiments were conducted on a die sinking EDM machine, model C-425 manufactured by the Electronica Industries, India. To conduct experiments with aluminium suspended distilled water as dielectric fluid, a separate dielectric re-circulating system has been fabricated and attached to the machine.

The work material chosen for the present study is W300 die-steel (0.32% C, 0.8% Si, 4.5% Cr, 1% Mn, 0.3% V and remaining Fe). It is extensively used in fabrication of tools and dies. The required sizes of workpieces were wire-cut from a blank. Electrolytic copper of diameter 9.5 mm was chosen as a tool electrode material. The experiments were conducted with powder mixed kerosene as dielectric fluids. External jet flushing with a pressure of 0.75 kPa was used for all the experiments. The metal powder selected was aluminium with average particle size of 27 μm. In this study face centered central composite design (FCCCD) was selected. FCCCD designs comprise a set of two-level factorial points, axial points and center runs. The factorial points contribute to the estimation of linear terms and two-factor interactions. The axial points contribute to the estimation of quadratic terms.

The controllable variables chosen for the experimentation were peak current (I), pulse on-time (T_on), concentration of the powder (C). Other factors such as gap voltage (35 V), machine servo sensitivity, lift time and flushing pressure were kept constant. The range of input parameters were fixed from the pilot experiments and the literature. The experimental conditions are shown in the Table 1. Metal removal rate (MRR) and average surface roughness ($R_a$) are the response parameters measured for all the experiments. MRR was measured by weight loss method and the $R_a$ values were measured by using stylus type roughness tester. For the selected three input process parameters the design consists of each 20 experiments using Al powder mixed with kerosene as dielectric fluid.
Table 1 Experimental Conditions

<table>
<thead>
<tr>
<th>Workpiece</th>
<th>W300 Die-steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workpiece size</td>
<td>20 mm×40 mm×6 mm</td>
</tr>
<tr>
<td>Electrode</td>
<td>Copper Ø9.5 mm</td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>35</td>
</tr>
<tr>
<td>Dielectric fluid</td>
<td>Al powder + distilled water</td>
</tr>
<tr>
<td>Polarity</td>
<td>positive</td>
</tr>
<tr>
<td>Peak current (A)</td>
<td>6, 12, 18</td>
</tr>
<tr>
<td>Pulse-on time (µs)</td>
<td>120, 220, 320</td>
</tr>
<tr>
<td>Powder concentration of powder (g/L)</td>
<td>0, 1, 2</td>
</tr>
<tr>
<td>Duty factor (%)</td>
<td>75</td>
</tr>
</tbody>
</table>

3. EMPIRICAL MODELLING

The Response Surface Methodology (RSM) was used to develop the quadratic regression equations for the output responses. RSM is a method which uses quantitative data from the experiments to determine and simultaneously solve multi variant equations. Values of correlation coefficients, R-Sq for MRR for kerosene over 0.95 and for $R_a$ it is over 0.85. The fit summary recommended that the quadratic model is statistically significant for analysis of MRR and $R_a$. The associated p-value for the models are lower than 0.05 (i.e. $\alpha = 0.05$, or 95% confidence) indicates that the developed empirical models (Eqs. 1-2) are statistically significant.[9, 10]

$$MRR \ (mg/\text{min}) = 15.32 + 7.31 I + 0.66 T_{on} - 2.52 C + 1.42 I \times I - 2.42 C \times I - 0.15 T_{on} \times C (1)$$

$$R_a (\mu m) = 4.45 + 0.66 I + 0.41 T_{on} - 0.62 C - 0.42 I \times I - 0.5 T_{on} \times T_{on} + 0.28 I \times T_{on} - 0.08 C \times I - 0.09 T_{on} \times C (2)$$

4. OPTIMIZATION USING NSGA-II ALGORITHM

The objective of the empirical modeling is to achieve higher MRR with a desired surface roughness. In this study, the responses such as MRR and $R_a$ obtained from the regression analysis (1-4) were selected to find the optimal combination of the process parameters. This multi-objective optimization problem is optimized using nondominated sorting genetic algorithm (NSGA-II)[11]. The multi-objective optimization problem for minimization of $1/MRR$, and $R_a$ is formulated for water fluid as below:

Maximize $MRR = f(I, T_{on}, C)$

and minimize $R_a = f(I, T_{on}, C)$

Subject to,

$$6 \leq I \leq 18$$

$$120 \leq T_{on} \leq 320$$

$$0 \leq C \leq 4$$

$$MRR > 0$$

$$R_a > 0$$

(3)
The optimization process starts with a random initial generation. First, the parents and offspring are combined to form a string. After calculating the objective functions of all strings in a generation, the solutions are classified into various non-dominated fronts. Then the crowded tournament selection operator is used to compare two solutions and returns the winner of the tournament according to two attributes:

(i) a non-dominated front in the population and (ii) a local large crowding distance. The first condition ensures that the chosen solution lies on a better non-dominated front, and the second condition ensures a better spread among the solutions. The simulated binary crossover (SBX) is used here to create two offspring from two-parent solutions. The random simplest mutation operator is applied randomly to create a solution from the entire search space.

The control parameters of NSGA-II are adjusted to give the best performance, which are: probability of crossover $p_c = 0.5$ with distribution index $\eta_c = 10$, mutation probability $p_m = 0.05$ and population size $p_z = 100$. NSGA-II with those control parameters produces better convergence and distribution of optimal solutions located along the pareto-optimal solutions [12]. A set of non-dominated solutions has been obtained with 1000 generations using NSGA-II and the best solution has been considered for validation by performing the experiments. The results were tabulated along with the percentage error in the Table 2. The maximum deviation observed between the predicted and experimental values are less than 10%.

Table 2 Optimal parameters from NSGA-II

<table>
<thead>
<tr>
<th>Response</th>
<th>For I=12A, $T_{\text{on}} = 180 \ \mu$s, $C = 4$ g/L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Predicted</td>
</tr>
<tr>
<td>MRR (mg/min)</td>
<td>9.94</td>
</tr>
<tr>
<td>$R_\alpha (\mu$m)</td>
<td>2.14</td>
</tr>
</tbody>
</table>

5. CONCLUSION
Based on the experimental results, conclusions can be drawn as follows: This research has proved that the PMEDM using Al powder and copper electrode is possible in improving the MRR and surface roughness of the W300 steel.

Formulation of empirical models for MRR and $R_\alpha$ by surface response methodology and multi-objective optimization of this models using NSGA-II resulted in simultaneously maximize MRR and to improve maximum possible surface roughness.

The optimal parameters obtained from NSGA-II algorithm for machining with Al powder mixed distilled water: I - 12A, $T_{\text{on}} - 180 \ \mu$s and C - 4g/L.

REFERENCES


