Investigation and analysis of EDM process – a new approach with Al₂O₃ nano powder mixed in sunflower oil

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Abstract. This study analyses the EDM process of AISI D2 steel with copper tungsten electrode along with Al₂O₃ powder mixed in sunflower oil as a dielectric fluid in place of EDM oil. AISI D2 steel is predominantly used in the manufacture of precision components of dies, press tools, automobiles, aircraft and space equipment. For that reason, it has been selected as work piece material. Based on the high conductivity nature of electrical and thermal characteristics of copper tungsten, it is used as an electrode in the process. Due to the easy availability and affordability, Al₂O₃ particles of 60 nanometer size is taken as catalyst for mixing with the sunflower oil and used as an alternate dielectric fluid in place of EDM oil. In order to reduce the harmful effects on the environment produced by the gases due to EDM oil, a vegetable oil namely, sunflower oil is used in its place. Flash point, fire point is higher than 300°C in sunflower oil when compared to conventional EDM oil. It is also eco-friendly and biodegradable. Input parameters of pulse interval, pulse duration, discharge voltage and peak current are compared with various output parameters of the process, namely, electrode wear rate, surface roughness and material removal rate. Experiments are conducted using Taguchi L9 experimental design and the effect of process input values over the output process response are analyzed using ANOVA method. The analysis leads to the conclusion that powder mixed EDM process (PMEDM), in which Al₂O₃nano particles mixed with sunflower oil yields a minimum surface roughness due to the better heat absorption. More removal of material along with a lesser tool wear is also noticed. Nano particles of Al₂O₃ improved the surface finish due to the abrasive action of the lowest discharge gap between particles.

1. Introduction
EDM is a non-conventional machining process using thermo electrical energy for removal of material. This process is used for machining of complex shape of precision components, critical components and more particularly, difficult to cut materials like titanium alloys and hard alloy castings [1, 2]. Applications are found mostly in aerospace, automobile and precision engineering. Electrical power is applied to create continuous sparks due to the gap between copper tungsten electrode and AISI D2 steel. Material removal takes place because of vaporizing due to melting and also due to ionization of dielectric oil [3]. The output process mainly depends on the input parameters like electrode gap, pulse interval, pulse duration and discharge voltage and peak current apart from work and tool materials. These input parameters influence the output responses namely, material removal rate, electrode wear rate and surface finish.
In this analysis, the effects of various parameters of PMEDM process are compared using both EDM oil and powder of Al2O3 mixed sunflower oil as dielectric fluid. Experimental design has been done using Taguchi technique and the responses have been evaluated using signal to noise ratio and ANOVA method [4,5].

2. Literature review
Based on the review of literatures, contributions of authors to this investigation and analysis of EDM process is discussed below:
Guu YH et.al [6] analyzed the effect of AISI D2 steel surface characteristics in EDM. Patel et.al. [7] analyzed different tool materials in EDM for their material removal rate and surface roughness. Jamadar et.al. [8] found the impact aluminium powder on machining on steel. According to Tzeng and Lee [9] nano particles up to 80 nano meter yielded a high surface finish, more material removal rate with less tool wear rate. Aliakbari and Baseri [10] optimized the EDM process parameters using Taguchi method with copper electrodes. Ng et.al. [11]observed that Canola and sunflower oils can replace conventional dielectric fluids due to the similar dielectric properties and erosion mechanisms. Satyarthi et.al. [12] investigated and found the release of aliphatic hydrocarbons, aerosols and benzene from hydrocarbon based dielectric fluids which impact the environment.

During the past, EDM performance information with a particular work piece and electrode of input process parameters for a specific dielectric fluid or powder is not sufficient. Furthermore, determination of powder size and process parameter variation is not still determined. The present experimental work concluded is meant to achieve the same.

3. Methodology
Experimental methodology is shown in figure 1.

4. Experimentation
4.1. Experimental setup
Experimental analysis has been carried out using a die sink EDM shown in figure. 2 consisting of a robust table for fixing the work piece, motorized fluid circulation system along with complete CNC controls. AISI D2 steel of 100mm x 60mm x 5mm work piece has been considered for the experimentation. Input parameters are 100 to 800 pulse time on, 40 to 80 volts and 3 to 8 amps. Dielectric fluids are EDM oil, sunflower oil and 60 nano meter powder of Al2O3 blended with sunflower oil. Copper tungsten is used as the electrode and surface roughness is recorded with Talysurf.
Effort is taken in exploring PMEDM process ability in increasing the metal removal rate of AISI D2 steel and reducing the electrode wear rate as well as the surface roughness. 60 nanometer powder of Al2O3 is mixed with sunflower oil and used as dielectric fluid. Figure 3 illustrates PMEDM process of powder mixed electrical discharge machining.

4.2. Material selection

4.2.1 Work material
For the manufacture of critical and precision components pertaining to dies, press tools, automobiles and space equipment, AISI D2 steel is preferred. Hence, AISI D2 steel is selected as the work piece material for the EDM process.

4.2.2 Electrode material
Due to the higher electrical and thermal conductivity, copper tungsten is selected as the electrode.

4.2.3 Dielectric fluid
Harmful gases are produced by the normally used hydrocarbon oils making the environment unsafe. To avoid the above issue, vegetable oil, namely, sunflower oil is selected due to the easy availability at affordable cost. 60 nanometer Al2O3 particles are mixed with sunflower oil and used as a dielectric fluid.
4.3. Process input parameters

The process input parameter values and levels are shown below:

| S.No. | FACTOR | PROCESS INPUT  | LEVEL |
|-------|--------|----------------|-------|
| 1.    | A      | Pulse time on  | 50    |
| 2.    | B      | Voltage        | 50    |
| 3.    | C      | Current        | 9     |

Table 1. Input parameters

| Ton   | Current I | Voltage V | SR   | MRR  | EWR  | S/N for SR | S/N for MRR | S/N for EWR |
|-------|-----------|-----------|------|------|------|------------|-------------|-------------|
| 50    | 9         | 50        | 3.47 | 2.42 | 0.15 | -10.92     | 7.01        | 16.71       |
| 150   | 9         | 50        | 3.99 | 2.61 | 0.08 | -11.97     | 8.33        | 21.51       |
| 200   | 9         | 50        | 4.56 | 4.11 | 0.10 | -13.12     | 12.28       | 20.18       |
| 50    | 12        | 70        | 2.41 | 1.98 | 0.02 | -9.14      | 5.95        | 33.15       |
| 150   | 12        | 70        | 2.67 | 2.88 | 0.03 | -9.60      | 9.19        | 33.14       |
| 200   | 12        | 70        | 2.64 | 0.83 | 0.04 | -9.780     | 11.60       | 28.40       |
| 50    | 15        | 100       | 3.27 | 1.04 | 0.05 | -10.80     | 4.17        | 25.51       |
| 150   | 15        | 100       | 4.16 | 2.63 | 0.06 | -12.78     | 8.41        | 25.50       |
| 200   | 15        | 100       | 3.45 | 2.85 | 0.07 | -10.85     | 9.11        | 23.22       |

Table 2. Experimental results with EDM oil as dielectric

| Ton   | Current I | Voltage V | SR   | MRR  | EWR  | S/N for SR | S/N for MRR | S/N for EWR |
|-------|-----------|-----------|------|------|------|------------|-------------|-------------|
| 50    | 9         | 50        | 0.76 | 7.2  | 1.2  | 2.43       | 17.15       | 1.58        |
| 150   | 9         | 50        | 0.75 | 12.8 | 0.5  | 0.82       | 22.2        | 6.38        |
| 200   | 9         | 50        | 0.69 | 10.9 | 0.2  | 2.05       | 17.84       | 17.22       |
| 50    | 12        | 70        | 0.70 | 8.7  | 0.68 | 2.73       | 18.80       | 3.10        |
| 150   | 12        | 70        | 0.18 | 11.6 | 0.19 | 1.83       | 21.29       | 14.89       |
| 200   | 12        | 70        | 0.29 | 11.1 | 0.4  | 2.78       | 20.90       | 7.96        |
| 50    | 15        | 100       | 0.80 | 8.0  | 0.9  | 2.97       | 18.06       | 0.92        |
| 150   | 15        | 100       | 0.86 | 7.1  | 0.8  | 3.31       | 17.02       | 1.94        |
| 200   | 15        | 100       | 1.30 | 8.3  | 0.8  | 0.10       | 18.40       | 1.31        |

Table 3. Experimental results with SF oil as dielectric

| Ton   | Current I | Voltage V | SR   | MRR  | EWR  | S/N for SR | S/N for MRR | S/N for EWR |
|-------|-----------|-----------|------|------|------|------------|-------------|-------------|
| 50    | 9         | 50        | 3.86 | 5.43 | 0.11 | -11.73     | 14.69       | 19.01       |
| 150   | 9         | 50        | 4.36 | 6.67 | 0.22 | -12.78     | 16.48       | 12.98       |
| 200   | 9         | 50        | 4.76 | 18.03| 0.26 | -13.56     | 18.03       | 11.59       |
| 50    | 12        | 70        | 6.48 | 23.84| 0.36 | -16.23     | 23.84       | 8.87        |
| 150   | 12        | 70        | 8.33 | 25.91| 0.41 | -18.41     | 25.91       | 7.54        |
| 200   | 12        | 70        | 9.28 | 27.95| 0.42 | -19.35     | 27.95       | 7.68        |
| 50    | 15        | 100       | 8.70 | 31.74| 0.44 | -18.79     | 31.71       | 7.07        |
| 150   | 15        | 100       | 10.85| 33.23| 0.52 | -20.71     | 33.23       | 5.66        |
| 200   | 15        | 100       | 11.93| 33.61| 0.56 | -21.53     | 33.61       | 5.02        |

Table 4. Experimental results with nano Al2O3 mixed SF oil as dielectric

5. Optimization

5.1. Taguchi method of approach

Performance of the products is described by some characteristics in relation to their expected requirements. Taguchi method statistically applies design and experimental analysis to improve the quality and productivity of the product with minimum simulation trials using orthogonal arrays. [13-15]
Particular design parameter quality evaluation is done using signal to noise ratio (S/N) got transformed from the loss function MRR and SR. Signal to noise ratio is analyzed as larger-the-better, nominal-the-better and smaller-the-better. Then parameter settings are established to have a robust product quality [16, 17]. Eco-friendly and sustainable approach is taken to avoid harmful gases released by the hydrocarbon oil with the alternate sunflower oil blended with Al₂O₃ as dielectric fluid. Output response results of MRR, EWR and SR during process with EDM oil, sunflower oil and Al₂O₃ mixed sunflower oil are compared.

5.2. Design of parameter characteristics
Aim of designing the parameter characteristics is to optimize the process input in improving the output response, thereby performance of the product and quality without a cost increase. Each characteristic differs in the S/N ratio analysis and not straight forward. Hence process optimization is left to the experimental configuration and engineering analysis. Application of higher ampere current increases material removal rate with a sacrifice in electrode wear and rough surface. Same is the case of fall in discharge voltage. Al₂O₃ powder blended sunflower dielectric fluid enhances material removal rate and surface finish with a reduction in wear of electrode. Due to proper concentration of particles, stabilization and effectiveness of process are achieved. Smaller particles of size 60 nano meter Al₂O₃ help to achieve a better surface finish.

5.3. L9 orthogonal array
On computing the degrees of freedom, appropriate orthogonal is selected for experiments [18]. Accordingly for experimentation, L9 orthogonal array is used. EDM oil, sunflower oil, 60 nano meter size Al₂O₃ mixed sunflower oil as dielectric fluid with copper tungsten electrode, nine experiments at various levels of parameters are conducted on the work piece material of AISI D2 steel. Each experiment is repeated thrice and average results are recorded.

5.4. Analysis of variance (ANOVA)
Statistical analysis technique ANOVA is used to investigate the results derived from the simulation trials. Significant effect of the process parameter on the performance is statistically found using F test. F value is the ratio of mean square deviation to the mean of square error. S/N ratio is found from the sum of squared deviations and mean of multi response. By applying this methodology and analyzing the vast array of data, investigated results are computed.

5.4.1  AISI D2 steel, copper tungsten and EDM oil

| Response | Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|----------|--------|----|--------|--------|---------|---------|
| SR       | Ton    | 2  | 0.5631 | 0.2815 | 2.19    | 0.228   |
|          | I      | 2  | 3.3084 | 1.6542 | 12.86   | 0.018   |
|          | Error  | 4  | 0.5147 | 0.1287 |         |         |
|          | Total  | 8  | 4.3862 |        |         |         |
| MRR      | Ton    | 2  | 0.8502 | 0.4251 | 0.44    | 0.670   |
|          | I      | 2  | 2.0058 | 1.0029 | 1.05    | 0.431   |
|          | Error  | 4  | 3.8360 | 0.9590 |         |         |
|          | Total  | 8  | 6.6920 |        |         |         |
| EWR      | Ton    | 2  | 0.000467 | 0.000233 | 0.37 | 0.713 |
|          | I      | 2  | 0.009800 | 0.004900 | 7.74 | 0.042 |
|          | Error  | 4  | 0.002533 | 0.000633 |       |         |
|          | Total  | 8  | 0.012800 |        |         |         |

5.4.2  AISI D2 steel, copper tungsten and SF oil

| Response | Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|----------|--------|----|--------|--------|---------|---------|
|          |        |    |        |        |         |         |
5.4.3 **AISI D2 steel, copper tungsten and SF oil with 60 nanometer Al2O3**

| Table 7. Analysis of variance for SF oil with nano Al2O3 as dielectric |
|-----------------------------|-------------------|
| Response | Source | DF | Adj SS | Adj MS | F-Value | P-Value |
| SR | Ton | 2 | 8.242 | 4.1211 | 10.13 | 0.027 |
| | I | 2 | 57.810 | 28.9052 | 71.08 | 0.001 |
| | Error | 4 | 1.627 | 0.4067 | | |
| | Total | 8 | 67.679 | | | |
| MRR | Ton | 2 | 62.92 | 31.01 | 2.77 | 0.176 |
| | I | 2 | 820.48 | 410.24 | 36.60 | 0.003 |
| | Error | 4 | 44.83 | 11.21 | | |
| | Total | 8 | 927.32 | | | |
| EWR | Ton | 2 | 0.019400 | 0.009700 | 17.64 | 0.010 |
| | I | 2 | 0.148200 | 0.074100 | 134.73 | 0.000 |
| | Error | 4 | 0.002200 | 0.000550 | | |
| | Total | 8 | 0.169800 | | | |

On the basis of ANOVA results, optimum process input parameters for the response of minimum surface toughness and electrode wear with maximum material removal rate are evaluated for the 3 cases of experiments.

6. **Results and discussion**

Process input parameters of pulse time, voltage and current are applied at three levels. Using L9 orthogonal array, Taguchi statistical method is adopted for the simulation of trials. Results of response from 3 sets of experiments are investigated by ANOVA technique. Presented results demonstrate the performance of sunflower oil to be better than the conventional EDM oil as dielectric fluid. The performance with Al2O3 blended sunflower oil as dielectric fluid is still superior since material removal rate is increased by 38% with reduced surface roughness and electrode wear as evident from the ANOVA results.

Flash point and fire point of sunflower oil is more than 300°c of the conventional EDM oil. Hence sunflower oil as dielectric fluid is safe to the environment and operator by lowering the risk of explosion. Processing time is also reduced up to 44% due to more material removal rate as observed from the results of experiments. This is a gain at the industrial level both economically and socially because of the productivity increase due to the more material removal and eco-friendly environment.

7. **Conclusion**

This investigation reveals the implications of various process input parameters of EDM process towards their output response. L9 orthogonal array of Taguchi experimental design along with ANOVA method is used for the analysis of the 3 cases. Usage of copper tungsten electrode on AISI D2 steel material in the
EDM process with EDM oil, sunflower oil and \( \text{Al}_2\text{O}_3 \) blended sunflower oil and their responses on material removal rate, surface roughness and electrode wear rate are analyzed. No significant improvement due to the input parameter interaction is noticed in all the cases. In the case of sunflower oil as dielectric fluid, emission of harmful gases are not there as compared to EDM oil since it is biodegradable and eco-friendly which makes it safe to environment. \( \text{Al}_2\text{O}_3 \) blended sunflower oil as dielectric fluid, considerable increase in material removal rate, with a reduction in surface roughness and electrode wear rate are achieved. Hence, it is concluded that 60 nanometer \( \text{Al}_2\text{O}_3 \) blended with sunflower oil as dielectric fluid along with the copper tungsten electrode gives a productivity improvement in the EDM process.

References

[1] Singaravel B, Shekar K C, Reddy G G and Prasad S D 2020 *Ain Shams Engineering Journal* **11** 143-147
[2] Mangapathi Rao Kusumba, Vinay Kumar Domakonda and Singaravel Balasubramaniyan 2020 *International Journal of Modern Manufacturing Technologies* **12**
[3] Kansal H K, Singh S and Kumar P 2007 *Journal of Manufacturing processes* **9** 13-22.
[4] Singaravel B, Prasad S D, Shekar K C, Rao K M and Reddy G G 2020 *Advanced Engineering Optimization Through Intelligent Techniques* 527-536
[5] Singaravel B, Shekar K C, Reddy G G and Prasad S D 2020 *Advances in Applied Mechanical Engineering* 1069-77
[6] Guu YH, Hocheng H, Chou CY and Deng CS 2003 *Mat. Sci. Eng* **358** 37-43
[7] Patel V D, Patel C P and Patel U J 2011 *International journal of engineering research and applications* **1** 394-397
[8] Jamadar M and Kavade M V 2014 *International Journal of Mechanical and Production Engineering* **2** 120-123
[9] Tzeng Y F and Lee C Y *The International Journal of advanced manufacturing technology* **17** 586-592
[10] Aliakbari E and Baseri H 2012 *The International Journal of Advanced Manufacturing Technology* **62** 1041-1053
[11] Ng P S, Kong S A and Yeo S H 2017 *The International Journal of Advanced Manufacturing Technology* **90** 2549-56
[12] Satyarthi M K and Bharti S 2010 *International Symposium on Fusion of Science & Technology New Delhi, India.*
[13] Singaravel B and Selvaraj T 2016 *Journal for Manufacturing Science and Production* **16** 183-187
[14] Singaravel B and Selvaraj T 2016 *Journal of Advanced Manufacturing Systems** **15** 1-11
[15] Balasubramaniyan S and Selvaraj T 2017 *Journal of the Chinese Institute of Engineers* **40** 267-274
[16] Singaravel B, Shankar D P and Prasanna L 2018 *Materials Today: Proceedings* **5** 13464-71
[17] Singaravel B and Selvaraj T 2017 *International Journal of Machining and Machinability of Materials* **19** 218-229
[18] Devaraj S, Ramakrishna M and Singaravel B 2020 *International Journal of Lightweight Materials and Manufacture* **4** 210-217