

# Optimization Of Twr In Edm Machning On H30 Alloys With Graphite Coated Electrodes

<sup>[1]</sup>Akula Neeraja <sup>[2]</sup>Dr K. Prasanna Lakshmi

<sup>[1]</sup>Research scholar, Department of mechanical Engineering, JNT University, Hyderabad.

<sup>[2]</sup>Professor, Department of mechanical Engineering, JNTUH college of engineering, Sultanpur. India

E- mail ID: <sup>[1]</sup>akulaneeraja80@gmail.com, <sup>[2]</sup>prasannakaujala@jntu.ac.in

**Abstract:** Electric discharge machining (EDM) is a non-conventional manufacturing process in which electrical discharges are used to obtain a desired shape. A dielectric liquid separates the tool electrode from the workpiece, which allows current discharges to remove material from the workpiece. In order to maintain mould finishing applications, tool wear rate is one of the most critical factors. Electrode developments with promising cost reductions are needed for major contact areas in material removal. This cost can be reduced by using ceramic substances like aluminum that are coated with graphite and attached to polymer inserts. For EDM machining of mould finished components, graphite coated aluminum and copper attached polymer inserts were assessed. The TWR was calculated using a pre-machined H30 mold base with a graphite coating of 0.8mm thick on both materials. As compared with graphite electrodes attached to aluminium copper, graphite coated electrodes returned better results by 15%.

**Key words:** EDM, TWR, Grapheme coating, H30, Optimization, Taguchi.

## 1. Introduction

In Electrical Discharge Machining (EDM), a form of non-traditional machining, material is removed from the work piece by use of electrical discharges or spark erosion that passes through the electrode while the work piece is submerged in dielectric fluid. How the micro-EDM coating affects the spark discharge procedure during material removal is substantial. Also, there has been a substantial improvement in the economic efficiency of employing electrode materials. Using a Cu-coated Al electrode reduced the electrode material cost by around 2.85 times. [1]. However, in order to determine if this method is economically viable, it is necessary to also assess the cost of the electrode coating process. Cu-coated electrodes on MWCNT bases greatly enhance MRR, TWR, HV, and surface topography during electrical discharge machining (EDM). [2]. The machined surface layer contains coating alloy materials, such as Cu and MWCNT, which will alter the surface's mechanical, physical, and chemical properties. An increase in MRR and decreases in TWR and SR were seen while using an EDM Cu electrode covered with Ag. [3]. This contributes to enhance EDM machining performance. Results from an analysis of the electrode coating materials used in EDM machining with WC, Cu, and Ag electrodes reveal that WC has the shortest MRR and TWR, whereas Cu coated WC has the biggest MRR and Ag coated WC has the second-smallest MRR. [4]. When compared to the WC electrode, the TiN-coated electrode had a 16.32% reduction in TWR, a 26% reduction in OVC, and an improvement of about 18.9% in machining efficiency [5]. Studies comparing the performance of TiN, Ag, and ZrN coated electrodes in EDM revealed that the former was superior, according to published studies on coated electrodes [6]. The TiN-coated electrode has the smallest EWR and OVC, whereas the Ag-coated electrode has the biggest. Coated electrodes in EDM will have varying effects on the process depending on the material's melting point, electrical conductivity, and thermal conductivity. [7]. A solution that may be employed effectively in finishing machining processes is the effective layer of Cu coating with Gr electrode by plating method. This layer improves the SR values of the machined surface [8]. When comparing coated and uncoated electrodes in EDM, the results showed a 92% reduction in TWR and a 62.5% reduction in OVC for the coated electrode, respectively, due to the Al<sub>2</sub>O<sub>3</sub> -TiO<sub>2</sub> coating [9]. The uncoated electrode has a substantially larger TWR than the Cu-ZrB<sub>2</sub> coated electrode.

## 2. Literature review

In this review on EDM to study process parameters, output responses, modelling, optimization and prediction of process. Different tools are used like copper, graphite, coated, cryogenic treated or additively

manufactured tools are used to study improvement of process characteristics **Ablyaz, T., Muratov [10]** In this study, electrode-tools with excellent electrical and thermal properties were manufactured for use in die-sinker Electrical Discharge Machining. The most common materials, nowadays, for the manufacture of electrode tools are copper and graphite **Mandal, P., & Mondal [11]** The enhancement of surface quality was also observed for the machined surface, which was generated during the machining with copper-based MWCNT composite coated electrode. **Karunakaran, K. [12]** This research focuses on machine-ability studies on EDM of Inconel 800 with Silver Coated Electrolyte Copper Electrode. The purpose of coating on electrode is to reduce tool wear. The factors pulse on Time, Pulse off Time and Peck Current were considered to observe the responses of surface roughness, material removal rate, tool wear rate **Chiou, A. H., Tsao, C [13]** This paper uses a Grey-Taguchi method to examine the optimization of process parameters for the micro EDM of high-speed steel alloy (SKH59), using tungsten carbide (WC) electrodes. **Shirguppikar, S. S [14]** In this research article an attempt has been made to study effect of thin film coating of titanium nitride (TiN) on tungsten carbide (WC) micro-electrode on tool wear rate (TWR), over cut (OC) and depth of machining (Z coordinator) during micro-drilling of Ti-6Al-4 V. **Huang, C. H [15]** This study uses the Taguchi method with an L<sub>9</sub> orthogonal array, a signal-to-noise (S/N) ratio, and an analysis of variance (ANOVA) to determine the performance characteristics for micro EDM milling operations. **Liu, Y., Wang [16]** Comparative experiments of EDM small hole machining using composite tools were carried out on die steel. The effects of nickel-coated composite electrode and diamond-nickel-coated composite electrode on tool length wear, tool side wear, and tool shape change were analyzed. **Chindaladdha, N [17]** The study aims to investigate the performance of EDM product which used graphite coated with the copper layer. The experiment designed by using Taguchi-grey relational approach based multi-response optimization to find the optimal electroplating parameters. **Alavi, F., & Jahan [18]** to investigate the effects of the micro-electro-discharge machining (micro-EDM) process parameters on the machining performance parameters, in order to understand the behavior of each process parameter as well as to find out their optimal values. **Baral, S. K [19]** In present work, INCONEL 625 work material is used. This material has wide range of applications in seawater components, petrochemicals, aircraft ducting system, jet engine applications etc. Two tools are used one is copper and other is coated copper tool. **Lin et al. [20]** worked on improving multiple performance of EDM machining by using fuzzy approach. Different input parameters such as workpiece polarity, duty cycle, and pulse on time, dielectric fluid and discharge voltage are considered to optimize MRR and electrode wear rate.

### 3. Methodology

Tools were prepared by using electrolytic process with graphite depositing on copper tip attached to polymer substance. The two light weight ceramic base metals knurled to a depth of 0.6mm for the electrode deposition of graphite for 0.8mm. A total of 36 hours dumped in the graphite particle mould in electrolysis process to maintain the desired shape of the electrode. The process of coating shown in figure1.

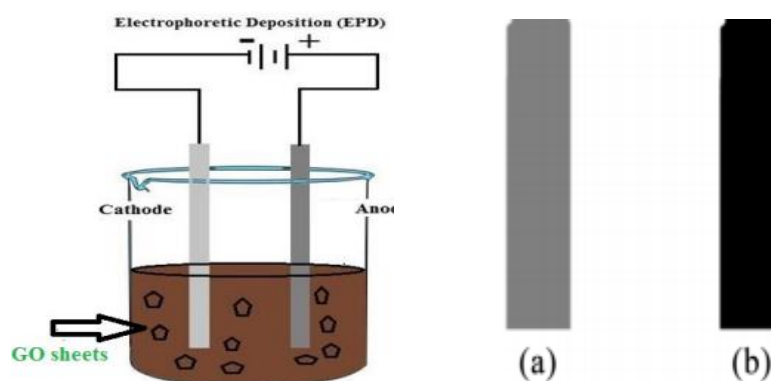


Figure 1: Electrodes before and after Graphite deposit

### 3.1 Experimentation on H30

Taguchi based L16 experimentation analysis has been done to compare the coated electrodes on both substances with 0.8mm thickness graphite layer electrodes for finishing applications of H30 material. 3 parameters with 4 levels taken in to consideration for the present work for MRR and TWR.

**Table1:** Process parameters for Taguchi

| S.NO | Parameters              | Level1 | Level2 | Level3 | Level4 |
|------|-------------------------|--------|--------|--------|--------|
| 1    | Current (A)             | 5      | 10     | 15     | 20     |
| 2    | Voltage(V)              | 40     | 45     | 50     | 55     |
| 3    | Pulse on time( $\mu$ s) | 100    | 500    | 1000   | 1500   |

Experiments has been carried out with L16 orthogonal array by varying the above parameters using the graphite coated ceramic electrodes on H30 work piece. The testimonials has been shown in the figure 2.



**Figure 2:** H30 plates after EDM machining

### 4. Results and discussions

H30 tool steel has application of mould making industries which offer difficulty in conventional machining in hardened condition. An efficient method for determining optimum process parameters for multiple performance characteristics, through integrating the grey relation theory with Taguchi method was discussed.

**Table 2:** Results of experiments for TWR

| S.NO | Input parameters |         |               | Output parameter(TWR)    |                                    |
|------|------------------|---------|---------------|--------------------------|------------------------------------|
|      | Current          | Voltage | Pulse on time | Copper- poly-G Electrode | Graphene Coated Aluminum electrode |
| 1    | 5                | 40      | 100           | 0.41                     | 0.45                               |
| 2    | 5                | 45      | 500           | 0.43                     | 0.50                               |
| 3    | 5                | 50      | 1,000         | 0.37                     | 0.46                               |
| 4    | 5                | 55      | 1,500         | 0.43                     | 0.49                               |
| 5    | 10               | 40      | 500           | 0.46                     | 0.53                               |
| 6    | 10               | 45      | 100           | 0.50                     | 0.59                               |
| 7    | 10               | 50      | 1,500         | 0.45                     | 0.60                               |
| 8    | 10               | 55      | 1,000         | 0.52                     | 0.62                               |
| 9    | 15               | 40      | 1,500         | 0.52                     | 0.54                               |
| 10   | 15               | 45      | 1,000         | 0.46                     | 0.57                               |
| 11   | 15               | 50      | 500           | 0.49                     | 0.61                               |
| 12   | 15               | 55      | 100           | 0.44                     | 0.58                               |
| 13   | 20               | 40      | 1,000         | 0.48                     | 0.63                               |
| 14   | 20               | 45      | 1,500         | 0.49                     | 0.65                               |
| 15   | 20               | 50      | 100           | 0.46                     | 0.52                               |
| 16   | 20               | 55      | 500           | 0.47                     | 0.53                               |

#### 4.1 Taguchi Analysis: G-C-P, G-C-A versus A, B, C

**Table 3:** Estimated Model Coefficients

| Term     | S/N ratios |         |          |       | Means    |         |         |       |
|----------|------------|---------|----------|-------|----------|---------|---------|-------|
|          | Coef       | SE Coef | T        | P     | Coef     | SE Coef | T       | P     |
| Constant | -16.0379   | 0.07784 | -206.042 | 0.000 | 6.34187  | 0.05554 | 114.182 | 0.000 |
| A 1      | 1.2478     | 0.13482 | 9.256    | 0.000 | -0.86313 | 0.09620 | -8.972  | 0.000 |
| A 2      | 0.2839     | 0.13482 | 2.106    | 0.080 | -0.23187 | 0.09620 | -2.410  | 0.053 |
| A 3      | -0.4247    | 0.13482 | -3.150   | 0.020 | 0.27813  | 0.09620 | 2.891   | 0.028 |
| B 1      | 0.2643     | 0.13482 | 1.961    | 0.098 | -0.16688 | 0.09620 | -1.735  | 0.133 |
| B 2      | 0.1215     | 0.13482 | 0.901    | 0.402 | -0.07062 | 0.09620 | -0.734  | 0.491 |
| B 3      | -0.0820    | 0.13482 | -0.608   | 0.565 | 0.03313  | 0.09620 | 0.344   | 0.742 |
| C 1      | 0.2853     | 0.13482 | 2.116    | 0.079 | -0.17062 | 0.09620 | -1.774  | 0.126 |
| C 2      | 0.3142     | 0.13482 | 2.331    | 0.059 | -0.23312 | 0.09620 | -2.423  | 0.052 |
| C 3      | -0.3322    | 0.13482 | -2.464   | 0.049 | 0.23313  | 0.09620 | 2.423   | 0.052 |

**Table 4:** Estimated Model Coefficients for StDevs

| Term     | Coef     | SE Coef | T      | P     |
|----------|----------|---------|--------|-------|
| Constant | 0.92101  | 0.03055 | 30.143 | 0.000 |
| A 1      | -0.23335 | 0.05292 | -4.409 | 0.005 |
| A 2      | -0.03359 | 0.05292 | -0.635 | 0.549 |
| A 3      | 0.05834  | 0.05292 | 1.102  | 0.313 |
| B 1      | -0.09016 | 0.05292 | -1.704 | 0.139 |
| B 2      | -0.04596 | 0.05292 | -0.868 | 0.419 |
| B 3      | 0.04066  | 0.05292 | 0.768  | 0.471 |
| C 1      | -0.04950 | 0.05292 | -0.935 | 0.386 |
| C 2      | -0.07778 | 0.05292 | -1.470 | 0.192 |
| C 3      | 0.08309  | 0.05292 | 1.570  | 0.167 |

**Table 5:** Analysis of Variance for SN ratios

| Source         | DF | Seq SS  | Adj SS  | Adj MS  | F     | P     |
|----------------|----|---------|---------|---------|-------|-------|
| A              | 3  | 12.1741 | 12.1741 | 4.05803 | 41.86 | 0.000 |
| B              | 3  | 0.7348  | 0.7348  | 0.24493 | 2.53  | 0.154 |
| C              | 3  | 1.4478  | 1.4478  | 0.48260 | 4.98  | 0.046 |
| Residual Error | 6  | 0.5816  | 0.5816  | 0.09694 |       |       |
| Total          | 15 | 14.9383 |         |         |       |       |

**Table 6:** Analysis of Variance for Means

| Source         | DF | Seq SS | Adj SS | Adj MS  | F     | P     |
|----------------|----|--------|--------|---------|-------|-------|
| A              | 3  | 6.1736 | 6.1736 | 2.05785 | 41.69 | 0.000 |
| B              | 3  | 0.3028 | 0.3028 | 0.10094 | 2.04  | 0.209 |
| C              | 3  | 0.6677 | 0.6677 | 0.22256 | 4.51  | 0.056 |
| Residual Error | 6  | 0.2962 | 0.2962 | 0.04936 |       |       |
| Total          | 15 | 7.4402 |        |         |       |       |

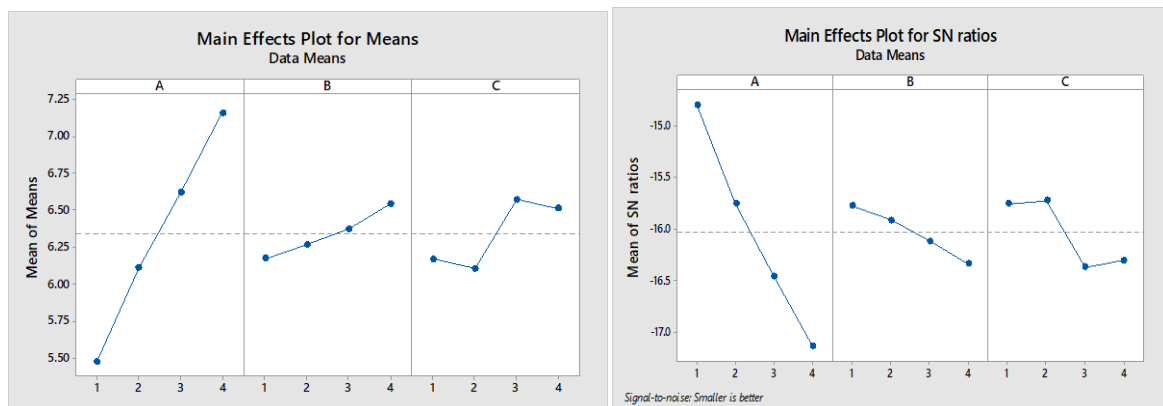
**Table 7:** Analysis of Variance for St.Devs

| Source         | DF | Seq SS  | Adj SS  | Adj MS  | F    | P     |
|----------------|----|---------|---------|---------|------|-------|
| A              | 3  | 0.40998 | 0.40998 | 0.13666 | 9.15 | 0.012 |
| B              | 3  | 0.08403 | 0.08403 | 0.02801 | 1.88 | 0.235 |
| C              | 3  | 0.06943 | 0.06943 | 0.02314 | 1.55 | 0.296 |
| Residual Error | 6  | 0.08962 | 0.08962 | 0.01494 |      |       |
| Total          | 15 | 0.65305 |         |         |      |       |

**Table8:** Response Table

| Level | Signal to Noise Ratios |        |        | Means |       |       | St. deviation |        |        |
|-------|------------------------|--------|--------|-------|-------|-------|---------------|--------|--------|
|       | A                      | B      | C      | A     | B     | C     | A             | B      | C      |
| 1     | -14.79                 | -15.77 | -15.75 | 5.479 | 6.175 | 6.171 | 0.6877        | 0.8309 | 0.8715 |
| 2     | -15.75                 | -15.92 | -15.72 | 6.110 | 6.271 | 6.109 | 0.8874        | 0.8750 | 0.8432 |
| 3     | -16.46                 | -16.12 | -16.37 | 6.620 | 6.375 | 6.575 | 0.9793        | 0.9617 | 1.0041 |
| 4     | -17.14                 | -16.34 | -16.31 | 7.159 | 6.546 | 6.512 | 1.1296        | 1.0165 | 0.9652 |
| Delta | 2.35                   | 0.57   | 0.65   | 1.680 | 0.371 | 0.466 | 0.4419        | 0.1856 | 0.1609 |
| Rank  | 1                      | 3      | 2      | 1     | 3     | 2     | 1             | 2      | 3      |

The analysis of optimization carried out for the tool wear rate by applying the optimized value option as “Smaller is better”.



**Figure3:** Means and S/N ratio plats for selected parameters



**Figure 4:** St. Devs of the TWR

Optimization of parameters from Taguchi carried out by using the Mini-tab software, the results and significance of parameters showing that the parameter current given major difference in tool wear as well as voltage have a consistency in TWR and maximum deviation found in pulse on time.

#### 4.2 Regression analysis

Regression analysis for the selected parameters interpreted for both the electrodes to find the tool wear rate affected in H30 machining.

Regression Analysis: G-C-P versus A, B, C Method

Categorical predictor coding (1, 0)  
Box-Cox transformation  $\lambda = 0.5$

**Table9:** Analysis of Variance for Transformed Response

| Source     | DF | Adj SS   | Adj MS   | F-Value | P-Value |
|------------|----|----------|----------|---------|---------|
| Regression | 5  | 0.207117 | 0.041423 | 55.01   | 0.000   |
| A          | 1  | 0.183169 | 0.183169 | 243.24  | 0.000   |
| B          | 1  | 0.005757 | 0.005757 | 7.65    | 0.020   |
| C          | 3  | 0.018192 | 0.006064 | 8.05    | 0.005   |
| Error      | 10 | 0.007530 | 0.000753 |         |         |
| Total      | 15 | 0.214648 |          |         |         |

Model Summary for Transformed Response

| S         | R-sq   | R-sq(adj) | R-sq(pred) |
|-----------|--------|-----------|------------|
| 0.0274416 | 96.49% | 94.74%    | 90.57%     |

**Table 10:** Coefficients for Transformed Response

| Term     | Coef    | SE Coef | T-Value | P-Value | VIF  |
|----------|---------|---------|---------|---------|------|
| Constant | 2.0705  | 0.0257  | 80.66   | 0.000   |      |
| A        | 0.09570 | 0.00614 | 15.60   | 0.000   | 1.00 |
| B        | 0.01697 | 0.00614 | 2.76    | 0.020   | 1.00 |
| C        |         |         |         |         |      |
| 2        | -0.0061 | 0.0194  | -0.32   | 0.759   | 1.50 |
| 3        | 0.0672  | 0.0194  | 3.46    | 0.006   | 1.50 |
| 4        | 0.0610  | 0.0194  | 3.14    | 0.010   | 1.50 |

**Table 11:** Regression Equation

| C |                                                       |
|---|-------------------------------------------------------|
| 1 | G-C-P <sup>0.5</sup> = 2.0705 + 0.09570 A + 0.01697 B |
| 2 | G-C-P <sup>0.5</sup> = 2.0644 + 0.09570 A + 0.01697 B |
| 3 | G-C-P <sup>0.5</sup> = 2.1377 + 0.09570 A + 0.01697 B |
| 4 | G-C-P <sup>0.5</sup> = 2.1315 + 0.09570 A + 0.01697 B |

Regression Analysis: G-C-A versus A, B, C

Categorical predictor coding (1, 0)

Box-Cox transformation  $\lambda = 0.5$

**Table12:** Analysis of Variance for Transformed Response

| Source     | DF | Adj SS  | Adj MS   | F-Value | P-Value |
|------------|----|---------|----------|---------|---------|
| Regression | 5  | 0.37306 | 0.074613 | 35.64   | 0.000   |
| A          | 1  | 0.31218 | 0.312180 | 149.13  | 0.000   |
| B          | 1  | 0.02223 | 0.022228 | 10.62   | 0.009   |
| C          | 3  | 0.03866 | 0.012885 | 6.16    | 0.012   |
| Error      | 10 | 0.02093 | 0.002093 |         |         |
| Total      | 15 | 0.39400 |          |         |         |

**Table 13:** Model Summary for Transformed Response

| S         | R-sq   | R-sq(adj) | R-sq(pred) |
|-----------|--------|-----------|------------|
| 0.0457536 | 94.69% | 92.03%    | 84.62%     |

**Table 14:** Coefficients for Transformed Response

| Term     | Coef    | SE Coef | T-Value | P-Value | VIF  |
|----------|---------|---------|---------|---------|------|
| Constant | 2.2004  | 0.0428  | 51.41   | 0.000   |      |
| A        | 0.1249  | 0.0102  | 12.21   | 0.000   | 1.00 |
| B        | 0.0333  | 0.0102  | 3.26    | 0.009   | 1.00 |
| C        |         |         |         |         |      |
| 2        | -0.0101 | 0.0324  | -0.31   | 0.761   | 1.50 |
| 3        | 0.0998  | 0.0324  | 3.09    | 0.012   | 1.50 |
| 4        | 0.0850  | 0.0324  | 2.63    | 0.025   | 1.50 |

**Table15:** Regression Equation

| C |                                                     |
|---|-----------------------------------------------------|
| 1 | G-C-A <sup>0.5</sup> = 2.2004 + 0.1249 A + 0.0333 B |
| 2 | G-C-A <sup>0.5</sup> = 2.1903 + 0.1249 A + 0.0333 B |
| 3 | G-C-A <sup>0.5</sup> = 2.3003 + 0.1249 A + 0.0333 B |
| 4 | G-C-A <sup>0.5</sup> = 2.2854 + 0.1249 A + 0.0333 B |

Fits and Diagnostics for Unusual Observations & Original Response

| Obs | G-C-A | Fit   |
|-----|-------|-------|
| 5   | 6.500 | 6.118 |

**Table16:** Transformed Response

| Obs | G-C-A' | Fit    | Resid  | Std Resid |
|-----|--------|--------|--------|-----------|
| 5   | 2.5495 | 2.4735 | 0.0760 | 2.10      |

**Discussions:** Taguchi regression analysis for the tool wear rate current is the main parameter affected, Puls rate also affected the wear.

## 5. Conclusions

Experiments conducted on H30 material with two electrodes coated with graphite has optimized and following conclusions were drawn:

- Graphite coated electrodes are good at the tool wear reduction, copper tip based polymer insert with graphite layer 0.8 given better results.

- Pulse on time given 1000 $\mu$ s given better result compared to others.
- Current at 10 amps given better tool life compared to aluminium electrode.
- Voltage 15V given better results for the present samples.

Microstructure with surface texture analysis need to be verified as further research to achieve better combination. Tool size also need to analyze for present design in computational tools are also appreciated

## References

- [1] ABLYAZ T., MURATOV K., PREETKANWAL S.B., SARABJEET S.S., 2019, Experimental Investigation of Wear Resistance of Copper Coated Electrode-Tool During Electrical Discharge Machining. IOP Conf. Ser.: Mater. Sci. Eng., 510, 012001, <https://doi.org/10.1088/1757-899X/510/1/012001>.
- [2] MANDAL P., MONDAL S.C., 2021, Performance Analysis of Copper-Based MWCNT Composite Coated 316L SS Tool in Electro Discharge Machining, Mach. Sci. Technol., 25, 422–437, <https://doi.org/10.1080/10910344.2020.1855652>.
- [3] KARUNAKARAN K., CHANDRASEKARAN M., 2017, Investigation of Machine-Ability of Inconel 800 in EDM with Coated Electrode, IOP Conf. Series: Materials Science and Engineering, 183, 012014. doi:10.1088/1757-899X/183/1/012014.
- [4] CHIOU A.H., TSAO C.C., HSU C.Y., 2015, A Study of the Machining Characteristics of Micro EDM Milling and its Improvement by Electrode Coating, Int. J. Adv. Manuf. Technol. 78, 1857–1864 <https://doi.org/10.1007/s00170-014-6778-3>.
- [5] SHIRGUPPIKAR S.S., PATIL M.S., 2020, Experimental Investigation on Micro-Electro Discharge Machining Process Using Tungsten Carbide and Titanium Nitride-Coated Micro-Tool Electrode for Machining of Ti-6Al4V, Advances in Materials and Processing Technologies, 8/1, <https://doi.org/10.1080/2374068X.2020.1833399>.
- [6] HUANG C.H., YANG A.B., HSU C.Y., 2018, The Optimization of Micro EDM Milling of Ti–6Al–4V Using a Grey Taguchi Method and its Improvement by Electrode Coating, Int. J. Adv. Manuf. Technol., 96, 3851–3859, <https://doi.org/10.1007/s00170-018-1841-0>.
- [7] LIU, Y., WANG W., ZHANG W., MA F., YANG D., SHA Z., ZHANG S., 2019, Experimental Study on Electrode Wear of Diamond-Nickel Coated Electrode in EDM Small Hole Machining, Advances in Materials Science and Engineering, 7181237, <https://doi.org/10.1155/2019/7181237>.
- [8] CHINDALADDHA N., KAEWDOOK D., 2020, Performance of Electroplated Copper Coating on Graphite Electrode in EDM Process, TNI Journal of Engineering and Technology, 8/1, 50–57.
- [9] PRASANNA J., RAJAMANICKAM S., 2016, Investigation of Die Sinking Electrical Discharge Machining of Ti-6Al-4V Using Copper and Al O -Tio Coated Copper Electrode, Middle-East Journal of Scientific Research, 24 (S1), 33–37, <https://doi.org/10.5829/idosi.mejsr.2016.24.S1.8>.
- [10] Ablyaz, T., Muratov, K., Preetkanwal, S. B., & Sarabjeet, S. S. (2019, April). Experimental investigation of wear resistance of copper coated electrode-tool during electrical discharge machining. In *IOP Conference Series: Materials Science and Engineering* (Vol. 510, No. 1, p. 012001). IOP Publishing.
- [11] Mandal, P., & Mondal, S. C. (2021). Performance analysis of copper-based MWCNT composite coated 316L SS tool in electro discharge machining. *Machining Science and Technology*, 25(3), 422-437.
- [12] Karunakaran, K., & Chandrasekaran, M. (2017, March). Investigation of Machine-ability of Inconel 800 in EDM with Coated Electrode. In *IOP conference series: materials science and engineering* (Vol. 183, No. 1, p. 012014). IOP Publishing.
- [13] Chiou, A. H., Tsao, C. C., & Hsu, C. Y. (2015). A study of the machining characteristics of micro EDM milling and its improvement by electrode coating. *The International Journal of Advanced Manufacturing Technology*, 78, 1857-1864.
- [14] Shirguppikar, S. S., & Patil, M. S. (2022). Experimental investigation on micro-electro discharge machining process using tungsten carbide and titanium nitride-coated micro-tool electrode for machining of Ti-6Al-4V. *Advances in Materials and Processing Technologies*, 8(sup1), 187-204.

- [15] Huang, C. H., Yang, A. B., & Hsu, C. Y. (2018). The optimization of micro EDM milling of Ti–6Al–4V using a grey Taguchi method and its improvement by electrode coating. *The International Journal of Advanced Manufacturing Technology*, 96, 3851-3859.
- [16] Liu, Y., Wang, W., Zhang, W., Ma, F., Yang, D., Sha, Z., & Zhang, S. (2019). Experimental study on electrode wear of diamond-nickel coated electrode in EDM small hole machining. *Advances in Materials Science and Engineering*, 2019, 1-10.
- [17] Chindaladdha, N., & Kaewdook, D. (2020). Performance of electroplated copper coating on graphite electrode in EDM process. *Journal of Engineering and Digital Technology (JEDT)*, 8(1), 50-57.
- [18] Alavi, F., & Jahan, M. P. (2017). Optimization of process parameters in micro-EDM of Ti-6Al-4V based on full factorial design. *The International Journal of Advanced Manufacturing Technology*, 92, 167-187.
- [19] Baral, S. K., Pallavi, P., & Utkarshaa, A. (2021). Effect of nichroloy coated electrode on machining performance of electrical discharge machining using Inconel 625. *Materials Today: Proceedings*, 45, 7894-7900.
- [20] J.L. Lin, K.S. Wang, B.H. Yan, Y.S. Tarng, optimization of electrical discharge machining process based on taguchi method with fuzzy logics, *J. Mater. Process. Technol.* 102 (2000) 48–55