Data Article

An extensive data set related to micro-drilling of Al-SiC-B₄C hybrid composite through μECM using GRA coupled PCA.

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A B S T R A C T

The emerging technique of micro electro mechanical systems throws a lot of challenging in the micro and nanoscale of machining. The present research explores the development of hybrid aluminium composite with hard particles boron carbide and silicon carbide in 10% volume fraction, and drilling of micro-holes using micro Electro Chemical Machining (μECM) process. The experiments were conducted based on Taguchi’s design of experiments. The chief drilling parameters considered for electrochemical drilling were frequency, voltage, current, and electrolyte concentration. The machining duration and electrode wear were observed as the machining responses. After the experimental trials, the observed machining responses were transformed into equivalent Multi Response Performance Index (MRPI) through Grey Relational Approach (GRA) approach. This MRPI were further analysed through Principal Component Analysis (PCA) so as to determine the exact interaction effect of each parameter on the machining responses. The supply current and electrolyte concentration were found to impact the responses at a bigger level, but frequency and voltage were at the meagre level. The research declared the purposeful finding of opti-
mized micro-drilling parameters of 30 Hz frequency, 8 V voltage, 16A current, and 0.4 mol of electrolyte concentration. The data presented in the articles are highly contributed to enhancing the micro-drilling process in terms of good process capability.

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### Specification Table

| Subject Area          | Mechanical Engineering          |
|-----------------------|--------------------------------|
| More specific subject Area | Micromachining                |
| Type of data          | Table, figure, and text file.  |
| How data was acquired | After completing each trial, the machining time was observed through stopwatch, and electrode tool wear was weighed through high precision electronic digital balance. |
| Data format           | Raw and analysed               |
| Parameters for data collection | The micro electrochemical machining parameters such as frequency of 30,60 and 90 Hz, voltage of 8,10 and 12 V, current of 0.8, 1.2 and 1.6 Amps, electrolyte concentration of 0.35, 0.4, and 0.45 mol were followed at three different levels. Aluminium 6061 alloy reinforced with 10% volume fraction of both SiC and B4C particles fabricated through stir casting setup was utilized as a work material. The hybrid Aluminium composite was cast to the geometry of Ø25 mm X 200 mm in length, and further, it was machined to a dimension of Ø25 mm X 2 mm thick disc using wire-cut EDM and well finished with surface grinding. The parameters considered for the micro Electro Chemical Machining (μECM) process were frequency, voltage, and current and electrolyte concentration at three varying levels. Taguchi’s L9 orthogonal array-based design sequence was followed to drill the micro holes. The machining time and electrode tool wear (EWR) were taken as chief objectives of the machining. The machining time was observed through stopwatch at each experimental trial and was recorded. The electrode tool wear was manipulated by subtracting the net weight of the drilled disc from the weight of the disc before being drilled, with the help of electronic digital balance. |
| Description of data collection | Data source location: Adama Science and Technology University, Adama, Ethiopia
Sona College of Technology, Salem, India |
| Data accessibility  | Data are available in this article and supplementary file |

### Value of the Data

- The data helps to arrive the efficient micro-drilling parameters through the μECM process to drill the micro holes in Al-B4C- SiC hybrid composite and to achieve the good process capability in an optimized way
- The data are found useful to highlight the various significant interaction effects on the micromachining objectives, which can be beneficial to the industrialist and fellow researchers to design efficient micro-drilling parameters.
- The presented data are following the combined GRA and PCA mathematical model, which can be utilized for further unconventional way of analysis
- The data presented in the article will be helpful to improve the quality and to minimize the production cost in emerging micromachining needs.

### 1. Data Description

Both the raw and analysed data are available in this article, which is related to the micro-drilling of Al-SiC-B4C hybrid composite using μECM. Tables 1, 2, and 3 depict the detailed me-
Table 1
Mechanical Properties of Aluminium 6061.

| Parameter       | Value       |
|-----------------|-------------|
| Elastic Modulus | 68.9 GPa    |
| Melting point   | 652 °C      |
| Hardness BHN    | 95          |
| Density         | 2.7 gm/cm³  |
| Yield strength  | 276 MPa     |
| Thermal conductivity | 167 W/mK |

Table 2
Mechanical Properties of Boron carbide.

| Parameter       | Value |
|-----------------|-------|
| Yield strength  | 569 MPa |
| Hardness (Vickers) | 38 GPa |
| Elastic Modulus | 460 GPa |
| Thermal conductivity | 42 W/mK |
| Melting point   | 2763 °C |

Table 3
Mechanical Properties of Silicon carbide.

| Parameter       | Value |
|-----------------|-------|
| Yield strength  | 5 - 9 GPa |
| Hardness (Vickers) | 26 GPa |
| Elastic Modulus | 410 GPa |
| Thermal conductivity | 3.8 W/mK |
| Melting point   | 2830 °C |

Table 4
Levels of μECM drilling parameters.

| Symbol | Process parameters | Units | Level 1 | Level 2 | Level 3 |
|--------|--------------------|-------|---------|---------|---------|
| A      | Frequency          | Hz    | 30      | 60      | 90      |
| B      | Voltage            | V     | 8       | 12      | 16      |
| C      | Current            | Amps  | 0.8     | 1.2     | 1.6     |
| D      | Electrolyte conc.  | Moles | 0.3     | 0.35    | 0.4     |

Table 5
Experimental layout and recorded response values using L9 orthogonal arrays.

| Experiment No. | Frequency (A) | Voltage (B) | Current (C) | Electrolyte conc. (D) | Machining time (mins) | Electrode Wear (mgm) |
|----------------|--------------|-------------|-------------|------------------------|-----------------------|----------------------|
|                | Level | Value (Hz) | Level | Value (V) | Level | Value (Amps) | Level | Value (mole) |               |             |
| 1              | 1     | 30         | 1     | 8         | 1     | 0.8         | 1     | 0.3         | 40             | 0.314       |
| 2              | 1     | 30         | 2     | 10        | 2     | 1.2         | 2     | 0.35        | 37             | 0.634       |
| 3              | 1     | 30         | 3     | 12        | 3     | 1.6         | 3     | 0.4         | 26             | 1.874       |
| 4              | 2     | 60         | 1     | 8         | 2     | 1.2         | 3     | 0.4         | 54             | 0.58        |
| 5              | 2     | 60         | 2     | 10        | 3     | 1.6         | 1     | 0.3         | 41             | 1.968       |
| 6              | 2     | 60         | 3     | 12        | 1     | 0.8         | 2     | 0.35        | 62             | 0.461       |
| 7              | 3     | 90         | 1     | 8         | 3     | 1.6         | 2     | 0.35        | 57             | 2.967       |
| 8              | 3     | 90         | 2     | 10        | 1     | 0.8         | 3     | 0.4         | 56             | 1.05        |
| 9              | 3     | 90         | 3     | 12        | 2     | 1.2         | 1     | 0.3         | 46             | 1.41        |

The mechanical properties of aluminium 6061 alloy, boron carbide, and silicon carbide respectively. The level of drilling parameters followed for the experiments are shown in Table 4. The sequence of experimental trials under Taguchi’s orthogonal array and corresponding recorded response values are tabulated in Table 5. The transformed data like S/N ratio, normalized S/N ratio, and grey coefficients under the GRA approach have been tabulated in Table 6. Table 7 depicts the value of grey coefficients and MRPI. The manipulated values of the principal components are shown in Table 8. The MRPI ranking of all parameter are shown in Table 9. The percentage of influence of each parameter has been shown in Table 10 through ANOVA. The plotting data for Fig. 3, 2(a), and 2(b) are presented in Table 11, 12, and 13 respectively. The ranking significance of each parameter through MRPI ranking has been shown in Fig. 1. The interaction plot for all parameters with responses is shown in Fig. 2(a) and 2(b). The adequacy and sufficiency of the
Table 6
S/N ratio, Normalized S/N ratio and Grey coefficients.

| Trial No | S/N ratio | Machining time | Electrode wear | Normalized S/N ratio | Machining time | Electrode wear | Grey coefficients | Machining time | Electrode wear |
|----------|-----------|----------------|----------------|----------------------|----------------|----------------|-------------------|----------------|----------------|
| 1        | 32.04     | -32.04         | -10.06         | 0.496                | 1.00           | 0.50           | 0.33              |                |                |
| 2        | 31.36     | -31.36         | -3.96          | 0.406                | 0.687          | 0.55           | 0.42              |                |                |
| 3        | 28.30     | -28.30         | 5.46           | 0.000                | 0.205          | 1.00           | 0.71              |                |                |
| 4        | 34.65     | -34.65         | -4.73          | 0.841                | 0.727          | 0.37           | 0.41              |                |                |
| 5        | 32.26     | -32.26         | 5.88           | 0.524                | 0.183          | 0.49           | 0.73              |                |                |
| 6        | 35.85     | -35.85         | -6.73          | 1.000                | 0.829          | 0.33           | 0.38              |                |                |
| 7        | 35.12     | -35.12         | 9.45           | 0.903                | 0.000          | 0.36           | 1.00              |                |                |
| 8        | 34.96     | -34.96         | 0.42           | 0.883                | 0.463          | 0.36           | 0.52              |                |                |
| 9        | 33.26     | -33.26         | 2.98           | 0.656                | 0.331          | 0.43           | 0.60              |                |                |

Table 7
Grey coefficients and MRPI.

| Trial No | Grey coefficients | Machining time | Electrode wear | Principal Component | Machining time | Electrode wear | MRPI |
|----------|-------------------|----------------|----------------|---------------------|----------------|----------------|------|
| 1        | 0.50              | 0.33           | 0.251          | 0.167               | 0.418          |                |
| 2        | 0.55              | 0.42           | 0.276          | 0.210               | 0.486          |                |
| 3        | 1.00              | 0.71           | 0.500          | 0.355               | 0.855          |                |
| 4        | 0.37              | 0.41           | 0.309          | 0.331               | 0.390          |                |
| 5        | 0.49              | 0.73           | 0.244          | 0.366               | 0.610          |                |
| 6        | 0.33              | 0.38           | 0.167          | 0.188               | 0.355          |                |
| 7        | 0.36              | 1.00           | 0.212          | 0.500               | 0.678          |                |
| 8        | 0.36              | 0.52           | 0.181          | 0.260               | 0.440          |                |
| 9        | 0.43              | 0.60           | 0.216          | 0.301               | 0.517          |                |

Table 8
Eigenvalues of principal components.

| Principal Component | Eigen Value | Percentage of contribution | Cumulative |
|---------------------|-------------|---------------------------|------------|
| PC1                 | 1.2070      | 60.4                      | 60.4       |
| PC2                 | 0.7930      | 39.6                      | 100        |

Table 9
MRPI ranking table.

| Parameters                        | Level 1 | Level 2 | Level 3 | Max-Min | Rank |
|-----------------------------------|---------|---------|---------|---------|------|
| Frequency (A)                     | 0.586   | 0.535   | 0.556   | 0.051   | 4    |
| Voltage (B)                       | 0.589   | 0.512   | 0.575   | 0.077   | 3    |
| Current (C)                       | 0.404   | 0.547   | **0.725** | 0.321   | 1    |
| Electrolyte Concentration (D)    | 0.515   | 0.517   | **0.645** | 0.13    | 2    |

Table 10
ANOVA table.

| Source                             | DF | Adj SS | Adj MS | F-Value | Percentage | Rank |
|------------------------------------|----|--------|--------|---------|------------|------|
| Frequency (A) Hz                   | 2  | 0.0039 | 0.0012 | 20.89   | 1.95       | 4    |
| Voltage (B) V                      | 2  | 0.0102 | 0.0051 | 52.63   | 5.02       | 3    |
| Current (C) Amps                   | 2  | 0.1553 | 0.0776 | 816.84  | 76.35      | 1    |
| Electrolyte Concentration (D)      | 2  | 0.0332 | 0.0166 | 174.94  | 16.35      | 2    |
| Error                              | 8  | 0.0007 | 0.00001| 0.33    |            |      |
| Total                              | 16 | 0.2034 |        |         |            |      |

R²=99.70 adjR² = 96.34.
proposed mathematical model are presented in Fig. 3. Raw data are available in the article and the analysed data related to graphs are also provided in the article.

2. Experimental Design, Materials, and Methods

2.1. Materials

Boron carbide particles and silicon carbide particles were utilized for the fabrication of aluminium composite. Aluminium 6061 alloy was used as matrix material and whose mechanical properties were given in Table 1. The mechanical properties of B₄C and SiC were given in Table 2 and Table 3 respectively [9]. The stir casting method was employed to cast the composite, and subsequently, wire cut EDM and surface grinding techniques were pressed into service to fabricate the composite disc of dimension Ø 25 mm x 2 mm thick. The electrode of 370 µm diameter made up of copper was used for drilling the required hole using µECM.
2.2. Methods

This µECM set up was composed of a work-holding device, a chemical tank with pump accessories, and a control panel. The control panel was used to control the movement of the electrode. The Electrode tool holding device was composed of an insulated Teflon plate with varying micro holes, so as to accommodate the varying sizes of the electrode. A microprocessor in build servo control was used to control the movement of the tool and to maintain the inter-electrode gap (IEG) automatically [1-3]. The Electrolyte flow unit constructed with a pump, nozzle, hose, and filters, was used to circulate the electrolyte around the machining zone with a constant velocity of 35 m/s. The flow of sodium nitrite as an electrolyte with high stream also helped to clean the machined micro debris present in-between tool and work material. The pulse rec-
Fig. 3. Biplot for machining time and electrode wear.

tifier assembled with μECM was employed to control the machining parameters like voltage, current, and frequency. During machining, the anodic electrode tool moved vertically downward to drill the required hole in cathodic work material by following the electrochemical dissolution of metal removal [4].

The experimental micro drilling was performed by following the experimental conditions shown in Table 4 and the level of parameters followed for the experiments is depicted in Table 5.

After completing each trial, the machining time was observed through stopwatch and the Electrode Tool Wear (ETW) was measured through weighing the weight loss occurred between, before the start of the trial and after the completion of the trial, using a high precision electronic balance.

2.3. Experimental design

2.3.1. Design of experiment

Taguchi’s design of experiment plays an important role to solve the intricate engineering issues by minimizing the number of experiments. L9 orthogonal array was used as an experimental design matrix, and the experiments were conducted. The values of the objectives have been recorded and shown in Table 5. To address the quality of process capability, the machining time required to drill the hole and the electrode wear rate were considered as chief drilling response for the present case, by extending the problem into the multi-response analysis.

2.3.2. Grey relational analysis

GRA can be an appreciable statistical tool to evaluate the issues with multi-level responses. The objective of the GRA is to reduce the multi responses into a single response by normalizing the values of the recorded response which vary between zero to one. Initially, the recorded experimental response values were manipulated to arrive at the S/N ratio by following larger the better or smaller the better case. The present objectives of the micro-drilling are machining time and electrode wear, which are to be required in a lower magnitude. The following relations were used to manipulate the S/N ratio and normalized S/N ratio. The computed S/N ratio and normalized S/N ratio are shown in Table 6.
For smaller the better type
\[
\frac{S}{N} \text{ ratio} = -10 \log \frac{1}{n} \sum_{i=1}^{n} Y_i^2 \tag{1}
\]

For normalization of the S/N ratio
\[
Z_{ij} = \frac{\max(Y_{ij}, i = 1, 2, \ldots, n) - Y_{ij}}{\max(Y_{ij}, i = 1, 2, \ldots, n) - \min(Y_{ij}, i = 1, 2, \ldots, n)} \tag{2}
\]

The following relation was followed to manipulate the grey relational coefficients,
\[
GC_{ij} = \frac{\Delta_{min} + \lambda \Delta_{max}}{\Delta_{ij} + \lambda \Delta_{max}} \tag{3}
\]

2.3.3. Principal component analysis (PCA)

Principal component analysis is one of the key statistical approaches to reduce the dimensionality of data set by preserving the variations present in the data set with the transformation of responses into a new data set called principal component. Based on the GRA approach, the recorded responses were normalized between the values of 0 to 1, and the same were utilized to manipulate the GRC and MRPI. Initially, the PCA determines the covariance matrix for the transformed data, subsequently, the eigenvectors and corresponding eigenvalues were manipulated with the following relations [6,7].

\[
\begin{bmatrix}
  x_1(1) & x_1(2) & \cdots & x_1(n) \\
  x_2(1) & x_2(2) & \cdots & x_2(n) \\
  \vdots & \vdots & \ddots & \vdots \\
  x_m(1) & x_m(2) & \cdots & x_m(n)
\end{bmatrix}
\]

Where \(x_i(j)\) advocates the value in the matrix, \(i=1,2,3,\ldots,m\) and \(j=1,2,3,\ldots,n\)

X is the grey relational coefficients of each response, “m” is the total number of experiments, and “n” is the total number of responses.

The coefficient of correlation array can be manipulated as
\[
R_{jl} = \frac{\text{Cov}(x_i(j), x_i(l))}{\sigma x_i(j) \times \sigma x_i(l)} \tag{4}
\]

Where Cov\((x_i(j), x_i(l))\) is covariance sequence of \(x_i(j)\) and \(x_i(l)\) and \(\sigma x_i(j)\), \(\sigma x_i(l)\) are the standard deviations of the sequence \(x_i(j)\) and \(x_i(l)\).

From the correlation coefficient array, eigenvectors and eigenvalues were calculated as follows,
\[
(R - \lambda_k I_m)V_{ik} = 0 \tag{5}
\]

Where \(\lambda_k\) are the eigenvalues \(\sum_{k=1}^{n} \lambda_k = nk = 1,2,3,\ldots,n\)

\(V_{ik} = [a_{k1}, a_{k2}, \ldots, a_{kn}]^T\) are the eigenvectors for the equivalent \(\lambda_k\) values

Principal component \(Y_{nk} = \sum_{i=1}^{n} X_m(i)V_{ik}\) \tag{6}

After the principal component analysis, the eigenvalues of each principal component have been arrived at and tabulated in Table 8.

Since the principal component with a larger eigenvalue retains the majority of variance, the largest eigenvalue of the principal component was considered for further manipulation of analysis of variance [8]. The weightage of MRPI of each variable was employed for the calculation of analysis of variance.

Table 9 shows the ranking effect of each parameter on the micro-drilling responses considered based on weightage. The current has the highest significant effect in comparison with the
other three parameters, chased by electrolyte concentration. The voltage and frequency have the meagre significance on the responses. The main effects plotted for MRPI and shown in Fig. 1 assure that the optimized level of micro-drilling parameters for improving the quality and process capability is $A_1B_1C_3D_3$.

Table 9 depicts the analysis of variance. The ANOVA table announces that the supply current carries a significant role to influence the responses followed by the electrolyte concentration. The effects of the other two parameters voltage and frequency do not have much impact over the responses.

From the interaction plots shown in Fig. 2(a) & (b), it is clear that the increase in supply current causes to more material removal thereby diminishing the machining time. The volume of metal removal is directly proportional to the supply current, which acknowledges the Faraday’s law. The increased value of current induces the irregular machined hole, which may be due to the clogging of metal debris between the inter-electrode gap. This phenomenon affects the drilling response electrode wear [5]. The interaction chart explores the fact that the increase in voltage also deteriorates the electrode surface due to the increased ionization of electrolytes. The combined effect of high current and low voltage ensures the reduction in machining time and electrode wear, which is once again endorsed with recommended optimized level of parameters voltage and current at B1C3 respectively.

As far as the interaction effect of electrolyte is concerned, the increased concentration of electrolytes paves the way for the formation of a large number of ions during drilling, subsequently increasing current density. This combined effect causes to reduce the machining time by increasing the metal removal rate.

Fig. 3 shows the biplot drawn between the first principal component and the second one. The observation annunciates that both the responses are near the value of one which upholds the significance of the responses. The distribution of data points uniformly without forming any cluster affirms that the recommended mathematical model for the present micro-drilling process analysis is highly adequate and sufficient.

Credit statement

Venkatesh Chenrayan: Conceptualization, Investigation, Writing original draft, Analyses and validation Mengistu Gelaw: Data curation Chandru Manivannan: Review and Editing, Venkatesan Rajamanickam: Supervision Ellappan Venugopal: Resources

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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