Mathematical Analysis of Process Parameters in Drilling of Various Aluminium Matrix Composites Using TOPSIS

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Abstract. Drilling is one of the major material removal processes to produce holes and the key parameters involved in the process are speed of the drilling tool and feed rate of the tool into the work piece to be machined. A conventional study would include the diameter of the drill bit as a key geometric feature that affects the output parameters: thrust, torque, roundness error and the surface roughness. Drilling experiments are performed on three different hybrid composite specimen of Al6061 alloy. Keeping the diameter constant and by varying the point angle of the tool, drilling is performed and the responses of the output parameters are recorded and tabulated. Using the data from the experiment, analysis of the data is done by one of the multi-criteria decision analysis method, TOPSIS. This method is used to determine the optimal condition to drill a particular specimen of the composite. In TOPSIS method, the data is ranked based on performance of the drill, to find the parameters which are ideal to obtain a hole with minimum roughness, circularity error and thrust force. But it is enough to keep the goal as minimum roughness because the other parameters will invariably get minimized as they are dependent.

1. Introduction

Metal matrix Composites (MMCs) usually consist of a low density metal such as Aluminium or magnesium reinforced with particulate or fibres of a ceramic such as Silicon Carbide and graphite. Compared with unreinforced metals, MMCs offer high specific strength and stiffness, higher operating temperature, and greater wear resistance, as well as the opportunity to tailor these properties for a particular application. Current markets for MMCs are primarily in the military and aerospace applications. Experimental MMC components have been developed for the use in aircraft, satellites, jet engines, missiles and space shuttles. The development is very important because it demonstrates that the MMCs are at least not prohibitively expensive for a very cost sensitive application [1,2]. Other commercial applications include cutting tools and circuit breaker contacts. Metal matrix composites with high specific stiffness and strength could be used in applications in which saving weight is an important factor [3]. Included in this category are robots, high speed machinery, and high-speed rotating shafts for ships and land vehicles. Good wear resistance, along with high specific strength, also favours MMC use in automotive engine and braking parts. Based on information now in public domain, the following military applications appear attractive: high temperature fighter aircraft engines and structures; high-temperature missile structures. Research and Development priorities include cheaper processes, cheaper materials, and coatings.
Dewangan et al studied the parameters of EDM and optimized the data set using TOPSIS and sensitivity analysis, to determine the best fit answer for the given constraints of weights of the data that is considered. They optimized the surface integrity for a given set of input parameters like voltage, material used, dielectric used etc [4]. They have also extended their concept to fuzzy TOPSIS, which is out of the scope of this paper. We shall be using the same concept as theirs and also as indicated in the forthcoming section so as to complete our analysis.

Tripathy and Tripathy used TOPSIS to optimize the material removal rate on using EDM in Aluminium matrix composites. They have used the concept illustrated beneath this section to optimize the material removal rate for a given composition of the material.[5].

2. Experimental Setup and Procedure

The three different specimen materials used in our study are aluminium alloy Al6061 with 5% weight fraction of boron carbide powders as first reinforcement along with 5% weight fraction of silicon carbide, 5% of Graphite powder and 5% of Mica as second reinforcement by stir casting technique and the specimen were prepared as a square slab of dimensions 100mm x 100mm x 10mm.

For the aim of finding the degree of influence of the drilling parameters, three drilling factors (spindle speed, feed rate and point angle) each at three levels are taken into consideration as shown in Table 1.

Taguchi [6] design of experiments has been selected to optimize the multiple performance characteristics. Accordingly, Taguchi based L27 orthogonal array is selected. The drilling experiments are conducted on the prepared hybrid composites specimen by vertical CNC machining centre and TiAlN coated carbide drill bits are used for drilling [7]. The response characteristics considered to study the parameters on drilling of Al Hybrid MMC Composite are thrust force, surface roughness [8] and circularity error. Three different levels of the drilling parameters are shown in Table 1.

| Table 1. Process Parameters and their levels |
|---------------------------------------------|
| Factor | Level 1 | Level 2 | Level 3 |
| Point Angle A [◦] | 108 | 118 | 128 |
| Speed B [rpm] | 1000 | 2000 | 3000 |
| Feed C [mm/rev] | 0.05 | 0.10 | 0.15 |

3. Measurement of Responses

The dynamometer with dynaware software is employed to record the response parameter, thrust force [9,10], throughout the drilling of the hybrid composite specimen. The surface quality of the drilled hole was characterized by its surface roughness value [11]. This response parameter, drilled hole surface roughness is measured with the help of surface roughness tester at Kosaka labs, Chennai. It was measured by moving the probe parallel to every hole axis from three totally different points and also the mean values are taken for analysis.

The next response parameter, circularity error was measured using three dimensional coordinate measuring machine (CMM) as given in [12] by V.N.Gaintonde at al. The experiments were conducted on three different specimen and the results of the three responses were tabulated as shown in Table 2.
4. Concept of TOPSIS

Technique for Order Preference by Similarity to Ideal Solution is what TOPSIS stands for. This technique is a popular way to analyze the variance in data and rank them as per the criterion specified by the method [13]. The basic technique involves this concept- the chosen alternative should have the shortest distance from the ideal solution and farthest distance from the negative ideal solution [14]. Decision matrix D consists of m alternatives and n attributes or criteria. It is shown below.

\[
D = \begin{bmatrix}
  x_{11} & \ldots & x_{1n} \\
  \vdots & \ddots & \vdots \\
  x_{m1} & \ldots & x_{mn}
\end{bmatrix}
\]

Hypothesis 1: Each Attribute in the Decision Matrix takes either monotonically increasing or monotonically decreasing utility.
Hypothesis 2: A set of weights for the attributes is required. The manipulation of the data set to compute and the order the data set from best to worst by ranking involves a series of 6 steps as elucidated below.

STEP 1: Construct the normalized decision matrix to transform the various dimensional attributes to the non-dimensional attributes which allow comparison between the attributes

\[ r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \]

STEP 2: Construct the weighted normalized decision matrix

\[
V = \begin{bmatrix}
 v_{11} & \cdots & v_{1n} \\
 \vdots & \ddots & \vdots \\
 v_{m1} & \cdots & v_{mn}
\end{bmatrix} \begin{bmatrix}
 w_{1r_{11}} & \cdots & w_{nr_{1n}} \\
 \vdots & \ddots & \vdots \\
 w_{1r_{m1}} & \cdots & w_{nr_{mn}}
\end{bmatrix}
\]

STEP 3: Determine the ideal and Negative-ideal solutions

\[
A^+ = \{ (\max_i v_{ij} | j \in J), (\min_i v_{ij} | j \in J') | i = 1,2,\ldots,m \} = \{ v_{1^+}, v_{2^+}, \ldots, v_{n^+} \}
\]

\[
A^- = \{ (\min_i v_{ij} | j \in J), (\max_i v_{ij} | j \in J') | i = 1,2,\ldots,m \} = \{ v_{1^-}, v_{2^-}, \ldots, v_{n^-} \}
\]

Where \( J = \{ j = 1,2,\ldots,n | j \text{ associated with benefit criteria} \} \)

and \( J' = \{ j = 1,2,\ldots,n | j \text{ associated with cost criteria} \} \)

STEP 4: Calculate the separation measure

Ideal separation \( S_i^+ = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_{j^+})^2} \), \( i = 1,2,3,\ldots,m \)

Negative–Ideal separation \( S_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_{j^-})^2} \), \( i = 1,2,3,\ldots,m \)

STEP 5: Calculate the relative closeness to the ideal solution

\[
C_i^* = \frac{S_i^-}{S_i^+ + S_i^-}, \quad 0 < C_i^* < 1, \quad i = 1,2,3,\ldots,m
\]

\[
C_i^* = 1 \text{ if } A_i = A^+
\]

\[
C_i^* = 0 \text{ if } A_i = A^-
\]

STEP 6: Rank the preference order. A set of alternatives can now be preference ranked according to the descending order of \( C_i^* \).
The experimental results on specimen 1 are normalized by the TOPSIS algorithm and the normalized values are tabulated in Table 3. Among the three responses, a higher weightage of 50% is given to surface roughness of the drilled hole and 25% weightages are given to both thrust force and roundness error. Based on this weightage, weighted normalized vectors are found and tabulated in the same table. Finally, by TOPSIS algorithm, the calculations are made to rank the 27 experiments and that also included in the table.

From the results we can see that the experiment 3 is ranked 1, which is having the parameters of 108°-point angle, 0.05 mm/rev feed rate and 3000 rpm speed.

| Normalised vectors | Weighted Normalised vectors | Dij+ | Dij- | Ci | Rank |
|--------------------|-----------------------------|------|------|----|------|
| Circularity error(mm) | Surface roughness (µm) | Thrust force (N) | Circularity error(mm) | Surface Roughness (µm) | Thrust force (N) |
| 0.1466 | 0.0994 | 0.0854 | 0.0366 | 0.0497 | 0.0214 | 0.0350 | 0.1921 | 0.8458 | 6 |
| 0.1415 | 0.0974 | 0.0661 | 0.0354 | 0.0487 | 0.0165 | 0.0328 | 0.1950 | 0.8560 | 5 |
| 0.1005 | 0.0355 | 0.0509 | 0.0251 | 0.0178 | 0.0127 | 0.0000 | 0.2266 | 1.0000 | 1 |
| 0.2020 | 0.1210 | 0.1454 | 0.0505 | 0.0605 | 0.0364 | 0.0550 | 0.1747 | 0.7604 | 13 |
| 0.1944 | 0.1155 | 0.0905 | 0.0486 | 0.0577 | 0.0226 | 0.0474 | 0.1823 | 0.7935 | 10 |
| 0.1537 | 0.1001 | 0.0824 | 0.0384 | 0.0501 | 0.0206 | 0.0358 | 0.1917 | 0.8426 | 7 |
| 0.2751 | 0.4493 | 0.2543 | 0.0688 | 0.2247 | 0.0636 | 0.2175 | 0.0283 | 0.1153 | 27 |
| 0.2714 | 0.1888 | 0.2034 | 0.0679 | 0.0944 | 0.0509 | 0.0957 | 0.1366 | 0.5881 | 18 |
| 0.2435 | 0.1515 | 0.1831 | 0.0609 | 0.0758 | 0.0458 | 0.0757 | 0.1563 | 0.6736 | 16 |
| 0.1532 | 0.1322 | 0.0966 | 0.0383 | 0.0661 | 0.0242 | 0.0514 | 0.1758 | 0.7738 | 11 |
| 0.1312 | 0.1086 | 0.0793 | 0.0328 | 0.0543 | 0.0198 | 0.0380 | 0.1892 | 0.8327 | 8 |
| 0.1026 | 0.0681 | 0.0661 | 0.0257 | 0.0341 | 0.0165 | 0.0167 | 0.2103 | 0.9263 | 2 |
| 0.2476 | 0.1957 | 0.2034 | 0.0619 | 0.0979 | 0.0509 | 0.0960 | 0.1336 | 0.5818 | 19 |
| 0.2233 | 0.1952 | 0.1526 | 0.0558 | 0.0976 | 0.0381 | 0.0892 | 0.1389 | 0.6089 | 17 |
| 0.1610 | 0.1712 | 0.1017 | 0.0403 | 0.0856 | 0.0254 | 0.0707 | 0.1575 | 0.6902 | 14 |
| 0.2934 | 0.3238 | 0.3560 | 0.0733 | 0.1619 | 0.0890 | 0.1700 | 0.0628 | 0.2697 | 26 |
| 0.2668 | 0.2686 | 0.3051 | 0.0667 | 0.1343 | 0.0763 | 0.1391 | 0.0918 | 0.3977 | 24 |
| 0.2533 | 0.2456 | 0.2034 | 0.0633 | 0.1228 | 0.0509 | 0.1181 | 0.1101 | 0.4826 | 22 |
| 0.1186 | 0.1060 | 0.1424 | 0.0297 | 0.0530 | 0.0356 | 0.0422 | 0.1858 | 0.8147 | 9 |
| 0.1175 | 0.0763 | 0.1220 | 0.0294 | 0.0382 | 0.0305 | 0.0274 | 0.2011 | 0.8800 | 3 |
| 0.1367 | 0.0918 | 0.1017 | 0.0342 | 0.0459 | 0.0254 | 0.0322 | 0.1946 | 0.8580 | 4 |
| 0.1436 | 0.2053 | 0.2390 | 0.0359 | 0.1027 | 0.0597 | 0.0976 | 0.1315 | 0.5739 | 20 |
| 0.1427 | 0.1637 | 0.1831 | 0.0357 | 0.0818 | 0.0458 | 0.0729 | 0.1546 | 0.6797 | 15 |
| 0.1292 | 0.1276 | 0.1627 | 0.0323 | 0.0638 | 0.0407 | 0.0544 | 0.1736 | 0.7615 | 12 |
| 0.2570 | 0.2747 | 0.3661 | 0.0642 | 0.1373 | 0.0915 | 0.1485 | 0.0878 | 0.3715 | 25 |
| 0.1711 | 0.2583 | 0.3000 | 0.0428 | 0.1292 | 0.0750 | 0.1288 | 0.1016 | 0.4409 | 23 |
| 0.1681 | 0.2259 | 0.2593 | 0.0420 | 0.1130 | 0.0648 | 0.1098 | 0.1190 | 0.5201 | 21 |
Table 4. Normalized Vectors of TOPSIS table for Specimen 2

| Normalised vectors | Weighted Normalised vectors |
|--------------------|-----------------------------|
| Circularity error (mm) | Surface Roughness (µm) | Thrust force (N) |
| 0.25 | 0.5 | 0.25 |
| Dij+ | Dij- | Ci | Rank |

The experimental results of specimen 2 are normalized similarly and the values are tabulated in Table 4. Again 50% weightage is given to drilled hole roughness 25% weightages are given to thrust force and roundness error each. In the same manner the weighted normalized vectors are found and tabulated. Finally, the ranking of all the experimental trials is done by TOPSIS algorithm and is tabulated in the last column of Table 4.

For the specimen 2, the optimum result (rank 1) is same as that of specimen 1. From the results we can see that the experiment 3 is ranked 1, which is having the parameters of 108°-point angle, 0.05 mm/rev feed rate and 3000 rpm speed.
manipulation is done by the steps indicated in the concept of TOPSIS, the above result is obtained. It and highest spindle speed, that is 

Similarly, The above Table 5 shows the results for the specimen 3. The maximum weight assigned is for the roughness values because that is the main response to be minimized, followed by thrust force and roundness error so as to utilize minimal effort to obtain the best result, and also as a concern to keep the tool from having more wear. After the data is manipulated, the result is obtained.

The $C_i$ values represent the overall quality measure of all the responses, because the $C_i$ values indicate the relative closeness to the ideal solution.

| Normalised vectors | Weighted Normalised vectors | $D_{ij}^+$ | $D_{ij}^-$ | $C_i$ | Rank |
|--------------------|-----------------------------|------------|------------|-------|------|
| Circularity error(mm) | Surface Roughness (µm) | Thrust force (N) | Circularity error(mm) | Surface Roughness (µm) | Thrust force (N) |
| 0.2269 | 0.1200 | 0.1129 | 0.0567 | 0.0600 | 0.0282 | 0.0458 | 0.1260 | 0.7331 | 10 |
| 0.1287 | 0.1643 | 0.1065 | 0.0322 | 0.0822 | 0.0266 | 0.0313 | 0.1280 | 0.8035 | 6 |
| 0.0669 | 0.1183 | 0.0980 | 0.0167 | 0.0592 | 0.0245 | 0.0057 | 0.1524 | 0.9640 | 1 |
| 0.1552 | 0.1970 | 0.1657 | 0.0388 | 0.0985 | 0.0414 | 0.0510 | 0.1081 | 0.6793 | 15 |
| 0.1361 | 0.2038 | 0.1467 | 0.0340 | 0.1019 | 0.0367 | 0.0500 | 0.1125 | 0.6922 | 14 |
| 0.0568 | 0.1633 | 0.1367 | 0.0142 | 0.0817 | 0.0342 | 0.0247 | 0.1381 | 0.8483 | 4 |
| 0.1722 | 0.2092 | 0.2107 | 0.0430 | 0.1046 | 0.0527 | 0.0623 | 0.0972 | 0.6095 | 20 |
| 0.0865 | 0.1678 | 0.2107 | 0.0216 | 0.0839 | 0.0527 | 0.0389 | 0.1245 | 0.7618 | 9 |
| 0.0442 | 0.1577 | 0.2097 | 0.0110 | 0.0788 | 0.0524 | 0.0342 | 0.1357 | 0.7989 | 7 |
| 0.1675 | 0.1890 | 0.1269 | 0.0419 | 0.0945 | 0.0317 | 0.0475 | 0.1125 | 0.7033 | 12 |
| 0.1188 | 0.1601 | 0.1200 | 0.0297 | 0.0800 | 0.0300 | 0.0285 | 0.1293 | 0.8192 | 5 |
| 0.1203 | 0.1278 | 0.1193 | 0.0301 | 0.0639 | 0.0298 | 0.0203 | 0.1383 | 0.8719 | 2 |
| 0.3626 | 0.2509 | 0.1738 | 0.0906 | 0.1255 | 0.0434 | 0.1053 | 0.0606 | 0.3652 | 26 |
| 0.1981 | 0.1909 | 0.1726 | 0.0495 | 0.0954 | 0.0432 | 0.0561 | 0.1009 | 0.6428 | 17 |
| 0.1209 | 0.2350 | 0.1688 | 0.0302 | 0.1175 | 0.0422 | 0.0639 | 0.1075 | 0.6271 | 19 |
| 0.0849 | 0.2972 | 0.2339 | 0.0212 | 0.1486 | 0.0585 | 0.0962 | 0.1048 | 0.5214 | 23 |
| 0.0559 | 0.2813 | 0.2252 | 0.0140 | 0.1407 | 0.0563 | 0.0875 | 0.1127 | 0.5628 | 21 |
| 0.0527 | 0.2965 | 0.2185 | 0.0132 | 0.1483 | 0.0546 | 0.0941 | 0.1137 | 0.5472 | 22 |
| 0.3786 | 0.1620 | 0.1360 | 0.0946 | 0.0810 | 0.0340 | 0.0869 | 0.0920 | 0.5141 | 24 |
| 0.1330 | 0.1718 | 0.1288 | 0.0333 | 0.0859 | 0.0322 | 0.0356 | 0.1226 | 0.7750 | 8 |
| 0.1028 | 0.1448 | 0.1280 | 0.0257 | 0.0720 | 0.0320 | 0.0209 | 0.1356 | 0.8666 | 3 |
| 0.2172 | 0.1479 | 0.1959 | 0.0543 | 0.0740 | 0.0490 | 0.0519 | 0.1084 | 0.6764 | 16 |
| 0.1470 | 0.1881 | 0.1866 | 0.0368 | 0.0941 | 0.0467 | 0.0487 | 0.1096 | 0.6923 | 13 |
| 0.1899 | 0.1538 | 0.1768 | 0.0475 | 0.0769 | 0.0442 | 0.0451 | 0.1127 | 0.7143 | 11 |
| 0.4844 | 0.1709 | 0.3617 | 0.1211 | 0.0855 | 0.0904 | 0.1309 | 0.0632 | 0.3254 | 27 |
| 0.2288 | 0.1795 | 0.3602 | 0.0572 | 0.0898 | 0.0901 | 0.0858 | 0.0869 | 0.5031 | 25 |
| 0.1550 | 0.1850 | 0.2510 | 0.0388 | 0.0925 | 0.0628 | 0.0578 | 0.1034 | 0.6414 | 18 |

**Table 5. Normalized Vectors of TOPSIS table for Specimen 3**
Higher values of $C_i$ show that the particular set of parameters in the corresponding trial would produce better responses. The combination of drilling parameters for the trial number 3 was found to have highest $C_i$ value in our experiments on specimen 1.

The main effect plots for relative closeness $C_i$ of specimen 1 are shown in Fig 1. Higher values give better results. It shows that the minimum point angle, minimum feed and maximum speed are desirable parameters for optimum results of drilling. This fig also shows that the influence of point angle in the performance of drilling is less when compared with speed and feed rate.

![Main Effects Plot for $C_i$ for Specimen 1](image1.png)

**Fig 1.** Main effects plot for relative closeness $C_i$ for specimen 1

Main effect plots for relative closeness $C_i$ of specimen 2 is shown in Fig 2. This figure shows that the influence of point angle, feed rate and spindle speed for specimen 2 is almost similar to specimen 1. Fig 3 shows the main effects plot for specimen 3.

![Main Effects Plot for $C_i$ for Specimen 2](image2.png)

**Fig 2.** Main effects plot for relative closeness $C_i$ for specimen 2
Influence of Point angle and Speed for specimen 3 is slightly differ from specimen 1 and 2 as shown in Fig. 3, but the influence of feed rate remain same.

Fig 3. Main effects plot for relative closeness $C_i$ for specimen 3

5. Conclusion
An attempt has been made to optimize the drilling parameters in drilling experiments of three different hybrid composite specimen of Al6061 based on L27 orthogonal array in vertical CNC Machining centre. The conclusions drawn from the experimental analysis are summarized below:

Optimal process parameters are obtained by the concept of TOPSIS which makes the multiple performance characteristics as a beneficial feature using simplified optimization procedure, and the optimal parameters are observed as point angle of 108°, feed rate of 0.05mm/rev and drilling speed of 3000 rpm.

The optimum drilling parameters produce the minimal roughness inside the drilled surfaces over the entire data set considered. Since we are considering roughness as the main criterion for deciding which is the best condition for drilling, maximum weightage is assigned to it for bringing the weighted normalized vectors.

Since the results are consistent for all the three specimens, we can conclude that the influence of reinforcements on the quality of drilling is minimal.

References
[1] Muhammad Aamir et al, 2020 A review: Drilling performance and hole quality of aluminium alloys for aerospace applications, *Journal of Materials Research and Technology* 9.6, 12484-12500.
[2] Saravanan S et al, 2020 Tribological behaviour of aluminum alloy (AA7075) based hybrid composites, *IOP Conference Series: Materials Science and Engineering* Vol. 923. No. 1.
[3] Mavhungu S T et al, 2017 Aluminum matrix composites for industrial use: advances and trends, *Procedia Manufacturing* 7 178-182.
[4] Dewangan S, Gangopadhyay S and Biswas C K, 2015 Study of surface integrity and dimensional accuracy in EDM using Fuzzy TOPSIS and sensitivity analysis, *Measurement* 63 : 364-376.
[5] Tripathy S, and Tripathy D K, 2016 Multi-attribute optimization of machining process parameters in powder mixed electro-discharge machining using TOPSIS and grey relational analysis, Engineering Science and Technology, an International Journal 19.1 : 62-70.

[6] Vankanti, Vinod Kumar, and Venkateswarlu Ganta, 2014 Optimization of process parameters in drilling of GFRP composite using Taguchi method, Journal of Materials Research and Technology 3.1 : 35-41.

[7] Narale M N et al, 2018 Experimental investigation and optimization of multiple performance characteristics of Al-Mica-B4C hybrid reinforced composite in drilling operation, Materials Today: Proceedings 5.9 : 19763-19772.

[8] Samy G S, and Thirumalai Kumaran S, 2017 Measurement and analysis of temperature, thrust force and surface roughness in drilling of AA (6351)-B4C composite, Measurement 103: 1-9.

[9] Rubi C, Sarala J, Udaya Prakash and Rajkumar C, 2020 Optimization of Process Parameters using Taguchi Technique for Drilling Aluminium Matrix Composites (LM6/B4C), IOP Conference Series: Materials Science and Engineering. Vol. 912. No. 3.

[10] Juliyana S, Jebarose and Udaya Prakash J, 2020 Drilling parameter optimization of metal matrix composites (LM5/ZrO2) using Taguchi Technique, Materials Today: Proceedings 33 :3046-3050.

[11] Senthil babu S, Vinayagam B K, 2015 Modeling and Analysis of Surface Roughness and Thrust Force in Drilling of Al Based Metal Matrix / Hybrid Composites, International Review on Modelling and Simulations (I.RE.M.O.S.), Vol. 8. N. 4 ISSN 1974-9821.

[12] Khaled Giasin and Sabino Ayvar-Soberanis, 2017 An investigation of burrs, chip formation, hole size, circularity and delamination during drilling operation of GLARE using ANOVA, Composite Structures 159 : 745-760.

[13] Arun Prasad K R et al, 2020 Optimization of turning parameters for Magnesium Silicon Carbide using TOPSIS method, IOP Conference Series: Materials Science and Engineering. Vol. 912. No.3.

[14] Ficko M et al, 2020 Multi-Response Optimisation Of Turning Process Parameters with GRA And TOPSIS Methods, International Journal of Simulation Modelling 19.4: 547-558.