Application of taguchi method coupled with GRA for optimization of drilling process parameters

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Abstract. In present article, an experimental study is performed for optimizing the machining parameters of AA6082. The control factors like cutting fluid (present - absent), speed (520 rpm – 420 rpm), feed rate (120 mm/min – 80 mm/min) and hole-depth (16 mm – 24 mm) are taken into account to optimize the material removal rate and surface roughness. Taguchi’s L₁₈ orthogonal array was chosen for experimental trials. Grey relational analysis is employed to find, which process parameters affect the surface finish most with their percentage contribution individually. The results of ANOVA show that among all the control factors, feed rate (74.82%) is the highest contributing factor followed by cutting fluid (11.42%). This study also shows that by using the taguchi approach, the surface finish of the machining process can be upgraded.

1. Introduction

For the sake of cost-effectiveness, increasing the quality grade of the machined component is the biggest difficulty in the global manufacturing industry. Over the past few years, the demand for the good surface finish in various machining operations has increased. Surface quality became a significant factor to judge the productivity of machined components.

Various machining operations like drilling, turning, milling etc. are widely used in manufacturing industries. Among these various machining processes Drilling is a versatile machining process used in machining shops and industries to get the desired product. Material is removed using a rotating cutting tool called drill bits in the form of burr in this process. Bit tool rotating at high speed is used to make a hole in solid material. A good surface finish is desired in every production process. It is one of the most important criteria for the evaluation of quality of the drilled hole. The small roughness can lead to affect the process and decrease the reliability of the product. This roughness factor gives a continuous need to study the optimization techniques of various parameters in the machining process to minimize the manufacturing cost and maximize the quality in terms of roughness.

Andrey Belyakov [1] discussed the mechanical behavior of various structural metals and their alloys. Various investigations regarding the micro structural changes in metallic materials when they are subjected to various machining processes are shown. Om Prakash Singh et al [2] performed an experiment by applying the GRA method to optimize the shoulder milling operation parameters. The study represents that in the optimization of cutting parameters of Al 6063, feed rate contributes the most. Arshad Noor Siddiquiee et al [3] emphasized on optimizing the drilling operation with the help of the taguchi approach. The experimental results revealed speed is the most important factor for surface roughness. The taguchi technique has been widely used in various analyses and by applying it, the time required for investigations can be saved. Avinash A Thakre and Julie Z Zhang et al [4-5] used the taguchi
technique to optimize the surface quality in different machining processes. Adem Cicek et al [6] investigated the drilling parameters and observed the effects on circularity lapse in drilling of SS 316 by taguchi technique under cryogenic treatment and observed that in reduction of roughness and hole size errors speed is a most leading factor. G Campatelli et al [7] studied the cutting forces of the milling process for aluminium 6082 and tried to develop a cutting force model for tangential cutting coefficient. Akhil K.T et al [8] tried to optimize the drilling characteristics using GRA. Glass reinforced polymer is chosen as material after noticing the increment in its use in automotive industry. M Subramanian et al [9] made a statistical model for investigation of cutting forces using RSM. Aluminium 7075 T6 was shoulder milled and a dynamometer was used to measure cutting forces. M S Sukumar et al [10] applied the taguchi approach for identification of the optimum conditions in milling of aluminium 6061. Lirong Zhou et al [11] suggested a multi-objective model to minimize the operation time and energy consumed for the end milling process of AISI 1045. Mohammad Aamir et al [12] reviews the details on drilling forces, drill tool geometry, drilling parameters, chip formation, hole metrics, analysis of tool wear, surface roughness, drill tool material and burr formation during machining of aluminium alloys. Gaurav Kumar et al [13] tried to optimize the end milling machining parameters while milling SS304. It is observed that coolant is the highest contributing factor. Mukesh Kumar et al [14] tried to optimize the machining parameters of deep drilling of SS321 by using the taguchi technique with GRA. The results revealed an improvement of 5.56%.

The literature survey shows that the Aluminium is the first choice of each and every industry especially for electrical and aerospace industry. Al 6082 is replacing 6061 in major industries. Rapidly increasing usage of 6082 is the major reason for selection of this material as a work piece. But there are certain problems related to machining of aluminium as it is a soft metal and selection of right cutting tool, cutting speed, evacuation of chip formed etc is important. While drilling of aluminium, heat generation is very large which lead to rubbing of tool with the material. This led to sticking of tool with the work piece and gives very poor surface finish and increases the rejection rate. In this article, the effects of various drilling parameters like cutting fluid, feed rate, hole-depth and speed on surface roughness were studied. The optimization was done using the taguchi technique.

2. Experimental Details

2.1 Work piece Material

Machined AA 6082 was used for the experiment. The sheet of 200×200×25 mm is taken to carry out the experiment which is shown in the Figure 1 a piece of 24 mm×24 mm is cut out from the sheet for composition test. The chemical constituents of the AA6082 is also shown below in Table 1.

![Figure 1. AA6082 Sheet](image)

| Table 1. Chemical constituents of AA6082 Material |
|-----------------|-----------------|
| Element         | % Constituents  |
| Silicon         | 0.765           |
| Iron            | 0.312           |
| Copper          | 0.024           |
Manganese 0.492
Magnesium 0.607
Zinc 0.029
Titanium 0.032
Chromium 0.030
Aluminium Balance
Lead 0.001
Tin 0.005
Nickel 0.012

2.2 VMC Machine
All the experiments were performed on the AA6082 sheet by the VMC machine available at Anushree Electicals Pvt. Ltd. Meerut as shown in Figure 2 and Mitotoyo tester was used for testing the surface roughness as shown in Figure 3.

![Figure 2. VMC Machine](image1)

![Figure 3. Mitotoyo Tester](image2)

The working conditions of the experiment are shown below in Table 2.

| Conditions           | Specifications          |
|----------------------|-------------------------|
| Specimen             | AA 6082                 |
| Size of specimen     | 200mm×200mm×25mm         |
| Diameter of drilled holes | 11 mm          |
| Machine              | VMC milling machine     |
| Tool                 | End mill 11mm           |
| Measuring instrument | Mitotoyo tester         |
| Cutting fluid        | Sherol BN               |

Work piece was cut into 5 pieces after machining with the aid of a power hacksaw to obtain the surface roughness measurements of eighteen drilled holes. The cross section of drilled holes after machining is shown in the Figure 4 and 5.
2.3 Experimental Design

$L_{18}$ orthogonal array is chosen for the design of experiment. On a VMC milling machine, all of the experiments were carried out. To find the optimized combination of multi performance factors, ANOVA was used. The four main machining parameters like cutting fluid, speed, feed and hole depth and feed were observed during drilling process as shown in Table 3.

| Process Parameters | Levels | Levels | Levels |
|--------------------|--------|--------|--------|
| A Cutting fluid    | Present| Absent | -      |
| B Speed (rpm)      | 520    | 470    | 420    |
| C Feed (mm/min)    | 120    | 100    | 80     |
| D Hole – Depth (mm)| 16     | 20     | 24     |

All 18 experiments were done according to taguchi’s experimental design. Mitotoyo’s tester was used to determine the roughness of drilled holes. The sampling length was taken 5.5 mm. MRR is calculated by equation 1 as given below.

$$MRR = \frac{\pi \times D \times D \times F}{4 \times 60} \text{ mm}^3/\text{sec}$$

F = feed rate (mm/min); D = diameter of drilled hole (mm), diameter of drilled holes is kept constant i.e., 11mm.

The calculated material removal rate and measured roughness evaluation is given in the Table 4.

| EXPERIMENT NO. | A | B | C | D | Ra(µm) | MRR (mm³/sec) |
|----------------|---|---|---|---|--------|---------------|
| 1              | 1 | 1 | 1 | 1 | 1.7    | 189.97        |
| 2              | 1 | 1 | 2 | 2 | 0.875  | 158.3         |
| 3              | 1 | 1 | 3 | 3 | 1.5    | 126.64        |
| 4              | 1 | 2 | 1 | 1 | 0.865  | 189.97        |
| 5              | 1 | 2 | 2 | 2 | 1.76   | 158.3         |
| 6              | 1 | 2 | 3 | 3 | 1.205  | 126.64        |
| 7              | 1 | 3 | 1 | 2 | 1.21   | 189.97        |
| 8              | 1 | 3 | 2 | 3 | 0.715  | 158.3         |
| 9              | 1 | 3 | 3 | 1 | 1.35   | 126.64        |
| 10             | 2 | 1 | 1 | 3 | 1.51   | 189.97        |
| 11             | 2 | 1 | 2 | 1 | 1.475  | 158.3         |
| 12             | 2 | 1 | 3 | 2 | 1.96   | 126.64        |
| 13             | 2 | 2 | 1 | 2 | 1.685  | 189.97        |
| 14             | 2 | 2 | 2 | 3 | 2.2    | 158.3         |
3. Analysis method
3.1 Analysis of Signal to Noise Ratio
The influential factors like noise factors and design parameters influence the product quality in taguchi’s design method. The Signal-to-Noise ratio takes the account of both; variability of results and mean, and generally depends on the characteristics to be optimized. The signal to noise ratios used in analysis are “nominal-the-better, lower-the-better and higher-the better”. The detailed equations are available in [15].

3.2 Grey relational generation
Grey relational generation is also called normalization. While using grey relational analysis one has to be cautious about preprocessing of data, as this analysis might give false conclusion if there exists a difference in factors, directions and goals. The transferring of real sequence to a parallel sequence is called data preprocessing. So, the standardization or normalization of the results are done in the range (0 - 1). The detailed equations are given in [16]

3.3 Normalization
After standardization, the grey coefficient is evaluated with the help of processed data to show the association of desired and real results which can be depicted as

\[ \xi_i(y) = \frac{\Delta_{minimum} + \zeta \Delta_{maximum}}{\Delta_{0i}(y) + \zeta \Delta_{maximum}} \]  

(2)

Where \( \Delta_{0i}(y) \) is the Deviation order of reference series \( x_0^*(y) \) and comparability order \( x_i^*(y) \), named as:

\[ \Delta_{0i}(y) = \|x_0^*(y) - x_i^*(y)\| \]  

(3)

\[ \Delta_{maximum} = \max_{ij} \min_{y} \|x_0^*(y) - x_i^*(y)\| \]  

(4)

\[ \Delta_{minimum} = \max_{ij} \min_{y} \|x_0^*(y) - x_i^*(y)\| \]  

(5)

\( \zeta \) is distinctive coefficient: \( \zeta \in [0,1] \). Normally \( \zeta = 0.5 \) is taken.

After calculating the grey coefficient, ANOM is done to attain the grey relational grade. ANOM is the average of the normalized data. To find the grey relational grade, equation is given below

\[ y_i = \frac{1}{n} \sum_{y=1}^{n} \xi_i(y) \]  

(6)

In actual scenario, the influence of each factor is different. So, equation (6) can be modified as:

\[ y_i = \frac{1}{n} \sum_{y=1}^{n} w_y \xi_i(y) \sum_{y=1}^{n} w_y \]  

(7)

where, \( w_y \) = the standardized weight of factor \( y \).

4. Results and discussions
The grey relational grade and coefficient obtained by analysis are investigated and presented in Table 5 and the optimization of drilling parameters is done.

Table 5. Values of grey relational grade

| Experiment No. | Grey relational coefficient | Grade | Order |
|----------------|----------------------------|-------|-------|
|                | Surface roughness | MRR   |       |
| 1              | 0.5956           | 1.000 | 0.7978| 2     |
| 2              | 0.3715           | 0.5265| 0.4490| 14    |
| 3              | 0.5348           | 0.3333| 0.4341| 15    |
| 4              | 0.3691           | 1.000 | 0.6845| 6     |
| 5              | 0.6150           | 0.5265| 0.5707| 10    |
| 6              | 0.4537           | 0.3333| 0.3935| 18    |
| 7              | 0.4550           | 1.000 | 0.7275| 5     |
| 8              | 0.3333           | 0.5265| 0.4299| 16    |
| 9              | 0.4925           | 0.3333| 0.4129| 17    |
| 10             | 0.5377           | 1.000 | 0.7688| 4     |
| 11             | 0.5276           | 0.5265| 0.5270| 11    |
| 12             | 0.6840           | 0.3333| 0.5087| 12    |
| 13             | 0.5908           | 1.000 | 0.7954| 3     |
| 14             | 0.7777           | 0.5265| 0.6521| 7     |
| 15             | 0.5924           | 0.3333| 0.4629| 13    |
| 16             | 1.0000           | 1.000 | 1.0000| 1     |
| 17             | 0.6696           | 0.5265| 0.5980| 8     |
| 18             | 0.8323           | 0.3333| 0.5828| 9     |

Figure 6. Response graph

It was observed from Figure 6 that the grey relational grade for feed decreases with increase in their levels, the value of grey relational grade increases with increase in levels of cutting fluid, hole-depth and speed. The dotted line shows the mean of grey relational level. Values of max-min for all parameters is also shown in Table 6 which depict that feed has maximum value of max-min i.e., 0.3299 and hence
ranked first, cutting fluid, speed and hole-depth are ranked second, third and fourth with reduced value as 0.1107, 0.0443 and 0.0326 respectively and it is also observed that grey relational grade are maximum at second level of cutting fluid, third level of speed, first level of feed and third level of hole-depth. So, $A_2B_3C_1D_3$ is the best combination of machining factors for optimization of drilling process parameters.

**Table 6. Response table**

| Symbol | Level1 | Level2 | Level3 | Max-Min |
|--------|--------|--------|--------|---------|
| A      | 0.5444 | 0.6551 | 0.6252 | 0.1107  |
| B      | 0.5809 | 0.5932 | 0.4658 | 0.0443  |
| C      | 0.7957 | 0.5378 | 0.4658 | 0.3299  |
| D      | 0.5805 | 0.6057 | 0.6131 | 0.0326  |

4.1 **Analysis of Variance**

Analysis of variance (ANOVA) is incorporated to find the significant effects of cutting parameters on the performance characteristics. To check these impacts, there is a tool $F$-test. When $F>4$, The variation in machining parameters has a high impact on quality characteristics.

**Table 7. Results of ANOVA**

| Symbol | Machining parameters | SS      | DOF | Mean square | F - ratio | % contribution |
|--------|----------------------|---------|-----|-------------|-----------|----------------|
| A      | Cutting fluid        | 0.0551  | 1.0000 | 0.0551     | 9.7346    | 11.42          |
| B      | Speed                | 0.0063  | 2.0000 | 0.0031     | 0.5545    | 1.30           |
| C      | Feed rate            | 0.3610  | 2.0000 | 0.1805     | 31.8923   | 74.82          |
| D      | Hole Depth           | 0.0035  | 2.0000 | 0.0017     | 0.3087    | 0.72           |
| Error  |                      | 0.0566  | 10.0000 | 0.0057    |           | 11.73          |
| Total  |                      | 0.4825  | 17.0000 |           | 100.0000  |                |

Table 7 gives the data of the contribution of taken cutting parameters on the characteristics of drilling process. Speed and hole-depth have very little effect on the performance characteristics.

![Figure 7. Contribution of process parameters](image)

The results of ANOVA proves that the feed rate has the maximum contribution (74.82 %) followed by cutting fluid (11.42%), speed (1.30%) and hole depth (0.72%) which is shown in Figure 7.

4.2 **Confirmation test**

The optimization is done using the taguchi’s method. Table 8 shows that the actual results and predicted results are in good agreement.
Table 8. Confirmation test results

|            | Prediction | Experiment | % change |
|------------|------------|------------|----------|
| Level      | A<sub>2</sub>B<sub>3</sub>C<sub>1</sub>D<sub>3</sub> | A<sub>2</sub>B<sub>3</sub>C<sub>1</sub>D<sub>3</sub> |          |
| Surface roughness | 1          | 1          |          |
| MRR        | 1          | 1          |          |
| Grey relational grade | 0.8898    | 1          | 12.39    |

5. Conclusions
The article is focused on taguchi’s technique to optimize the drilling process parameters since it is an easy and systematic way to do so. Findings for finest optimum combination of multi-performance parameters of drilling of AA 6082 is A<sub>2</sub>B<sub>3</sub>C<sub>1</sub>D<sub>3</sub> that is with cutting fluid absent, speed 420 rpm, feed of 120 mm/min and hole-depth 24 mm. The results obtained from ANOVA prove that the feed is the highest impactful factor chased by cutting fluid, speed and hole-depth. By applying this method, an improvement of 12.39% is observed.

The future scope is that more optimization methods like ANN model, genetic algorithms, cuckoo search, RSM, etc can be applied for analysis. There is always a chance of betterment.

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