Machining process parameters optimization of Aluminium Alloy AA6262 T6 for CNC Turning by Grey Relational Analysis

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Abstract: This research paper is based on the optimization for machining parameter of turning process of CNC M/C tool on aluminium alloy with the help of grey relation analysis. The parameters is found out the experiments perform on aluminium alloy AA6262T6. Machining operation is performed under dry cutting condition by uncoated carbide insert tool. In this research work operation parameters like feed, speed and depth of cut is optimized with output of material removal rate and surface roughness. In the present work, grey relation grade is used as a tool for optimization technique. The result is obtained by grey relation grade find out through grey relation analysis. The experiment outcomes are clear that the response in turning process can be increase efficiency from this fresh approach. To validate the test result, the confirmation test is performed. Prediction of GRA shows the noteworthy increment of 16.629 (14.55 %) in Material Removal Rate (MRR) and a noteworthy reduction of 0.148 (8.9%) in Surface Roughness.

Keywords: CNC turning, Surface Roughness, Gray Relation analysis (GRA), Taguchi, Optimization.

1. Introduction

Due to increase in demand it is required to find pot the materials which have high specific strength and stiffness and light-weighting, better fuel efficiency, and better payload. To reach the industrial objective it is need to optimise the machining process parameters like speed, feed and depth of cut[1]. In this paper review the optimization method i.e grey relation analysis in taguchi method used for optimize the machining process parameters of turning process on aluminium alloy AA6262 T6 on CNC turning machine tool. [2, 3]. In many industrial as well as daily application like nut-bolts, screws, coupling, marine fittings, pins, Oil pipe line fitting, and Valves we used Aluminium alloy AA6262 T6. So for the faster production it is required to optimize of machining parameter[4]. In the experiment consider three parameters speed, feed and depth of cut because it is an important factor for the optimization process with three levels.

An experiment had execute for maximum material removal rate (MRR) and minimum surface roughness because for any machining process it’s play important role[5]. The outcome of the experiment clears that the approach which is applied to the experiment has increased efficiency. For any product it is important to achieve high surface roughness for better finish.[6]. There is an goal of the industry to achieve the material removal rate in minimum time [7, 8]. For reduce the per product cost it is required to to reduce the production cost and the production time and the increase productivity. The experiment has been performed by orthogonal L27 array with grey relation analysis (GRA) with multiple responses [9, 10].

Saravananukumar et al. [11] has find out the optimisation of machining process parameter by grey relation analysis in taguchi method and find out that the feed has controlling factor as compared to speed and depth of cut. P. Jayaraman [12] has also applied the optimisation method for the machining process parameter by the grey relational analysis and find out that the feed is the most dominant factor for the optimisation follow by depth of cut and speed.[13, 14].
Babu [15] has applied the method for finding the reaction of machining process parameter on the surface roughness for the turning of hybrid metal matrix composite (Al-SiC-B4C) and find out that feed is the most important factor which affect the surface roughness as compared by cutting speed. Rajasekaran et al [16] use the taguchi method to find out the optimise machining process parameter for the good surface roughness of the turning cycle of CFRP composite with a ceramic tool and find out that the heat is the dominant factor from all the cutting process parameters as compared by speed and depth of cut. Abhang [17] applied the taguchi method for finding the effect of the three cutting parameters feed rate depth of cut and the lubricant temperature on the surface roughness for the turning of EN31 steel and find out that the depth of cut and the lubricant temperature is the main parameter that influence the surface roughness.

2. Experiment Set-up

2.1 Machining Process

It has a method to obtain the desired product with the raw material on the and finished product. Each experiment performs on prescript value for the operation and fixed levels of an experiment. Machining process involved the many parameters like speed, feed and depth of cut to achieve the finished product. This process parameter is depend on the many factors like a product shape size and the geometry,[18]. In which grey relational analysis is used as a optimisation method. [19, 20].

2.2 Machine Tool

Our experiment has been performed on the machine tool which has CNC turning Centre make Speed Turn, Model ST – 400 G X750 (Siemens 808D) has mentioned in Fig. 1 and machine detail shown in Table 2. The parameters which has been considered in the our experiment is feed speed and depth of cut. Our experiment is accomplish on the three level and the three parameters shown in Table 1[11, 21, 22].

2.3 Tool Holder

Tool holder is the important machine component of our machine tool it is used for precisely and accurately hold the tool in their place. The specification of the tool holder wont to study the effectiveness of Grey relational analysis is SDSCR 12 12 11 F3 while the specification of the tool holder wont to study and compare the effectiveness of varied optimization techniques is SDJCR 2525 [23]. Stellite-carbide and carbide tools can withstand still higher speeds. The heat resistant tools could also be used for high feeds than other tool material.
2.4 Experimental Plan
Standard array L27 is used for optimization calculation. It is used for array have three levels and three parameters. The following levels and parameters have been selected after performing many experiments. With variable change data also varies. Machining variables and levels are shows in Table.1.

| Parameters (Variables) | Stage 1 | Stage 2 | Stage 3 |
|------------------------|---------|---------|---------|
| Feed                   | 0.05    | 0.08    | 0.11    |
| Speed                  | 700     | 900     | 1100    |
| Depth of cut           | 0.8     | 1.2     | 1.6     |

\[
MRR = fxvxd
\]
\[
v = (\pi Dx s)/60
\]

Where
- \(MRR\) = Material removal rate (mm\(^3\)/sec)
- \(d\) = Depth of cut (mm)
- \(D\) = Original diameter (mm)
- \(s\) = Speed (RPM)
- \(f\) = Feed (mm/rev)
- \(v\) = Velocity (mm/sec)
- SR = Surface roughness (μm)[24]

2.5 Surface Roughness Tester
In this experiment the tester which is used for surface roughness is Mitutoyo SJ-210 4mN. With the help of this we calculate the surface roughness of work piece. Positioning the SR tester in the measurement target and then visually inspected the surface of the target and find out the value of surface roughness[11]. For find out the minimum surface roughness this process is repeated many times. And get experimental values. [23, 25].

2.6 Work piece Material
The Material which is used in this work for the experiment performed is Aluminium alloy AA6262 T6 due to their mechanical and chemical properties like good corrosion resistance and heat treatable alloy with high strength. It also has a good surface finish and machinability. Aluminium alloy AA6262 T6 is used for Oil line fitting, and Valves, screw, marine fitting, nuts, coupling, Hinge pin.

![Figure 2](image_url) (a) Workpiece post Machining. (b) Drawing of the Work piece[24]
3. Grey Relation Analysis (GRA)

GRA relation analysis is applied for the optimization in which multi variable is converted into a single variable. In this calculation we consider the material removal rate maximised and surface roughness has minimised.[26]. The giving steps are follows to find out the GRG [13, 14].

**Step 1: Grey Relation Generation**

First offal we calculate the normalized value of the experiment.

| Exp. No. | Speed | Feed | DOC | SR | MRR |
|----------|-------|------|-----|----|-----|
| 1        | 700   | 0.05 | 0.8 | 0.516 | 29.746 |
| 2        | 700   | 0.05 | 1.2 | 0.491 | 44.619 |
| 3        | 700   | 0.05 | 1.6 | 0.409 | 59.493 |
| 4        | 700   | 0.08 | 0.8 | 0.58  | 47.594 |
| 5        | 700   | 0.08 | 1.2 | 0.515 | 71.391 |
| 6        | 700   | 0.08 | 1.6 | 0.666 | 95.188 |
| 7        | 700   | 0.11 | 0.8 | 0.741 | 65.442 |
| 8        | 700   | 0.11 | 1.2 | 0.731 | 98.163 |
| 9        | 700   | 0.11 | 1.6 | 1.515 | 130.884 |
| 10       | 900   | 0.05 | 0.8 | 2.68  | 38.245 |
| 11       | 900   | 0.05 | 1.2 | 1.017 | 57.368 |
| 12       | 900   | 0.05 | 1.6 | 1.515 | 130.884 |
| 13       | 900   | 0.08 | 0.8 | 1.433 | 61.192 |
| 14       | 900   | 0.08 | 1.2 | 0.72  | 91.788 |
| 15       | 900   | 0.08 | 1.6 | 1.711 | 122.385 |
| 16       | 900   | 0.11 | 0.8 | 0.71  | 84.139 |
| 17       | 900   | 0.11 | 1.2 | 0.524 | 126.209 |
| 18       | 900   | 0.11 | 1.6 | 0.482 | 168.279 |
| 19       | 1100  | 0.05 | 0.8 | 3.95  | 46.744 |
| 20       | 1100  | 0.05 | 1.2 | 1.711 | 70.116 |
| 21       | 1100  | 0.05 | 1.6 | 0.554 | 93.488 |
| 22       | 1100  | 0.08 | 0.8 | 8.38  | 74.791 |
| 23       | 1100  | 0.08 | 1.2 | 2.691 | 112.186 |
| 24       | 1100  | 0.08 | 1.6 | 1.077 | 149.581 |
| 25       | 1100  | 0.11 | 0.8 | 2.726 | 102.837 |
| 26       | 1100  | 0.11 | 1.2 | 3.555 | 154.256 |
| 27       | 1100  | 0.11 | 1.6 | 1.663 | 114.255 |

We calculate the normalised value for material removal rate Maximised and surface roughness is minimised.

\[
(x_i^*(k)) = \frac{x_i^k(k) - \min(x_i^0(k))}{\max(x_i^0(k)) - \min(x_i^0(k))} \tag{3}
\]

We calculate the normalised value for material removal rate Maximised and surface roughness is minimised.

\[
(x_i^*(k)) = \frac{\max(x_i^0(k)) - x_i^k(k)}{\max(x_i^0(k)) - \min(x_i^0(k))} \tag{4}
\]
**Step 2** For each experiment deviation sequence is calculated show in table 5.

**Step 3** GR Coefficient is calculating as surface Roughness and MRR.

\[
\zeta_i (k) = \frac{\Delta_{\min} + \mu \Delta_{\max}}{\Delta_{0i}(k) + \mu \Delta_{\max}}
\]

(5)

\[
\Delta_{0i}(Y)\text{ has deviation sequence} \ \ \ \ \ \Delta_{0i}(Y) = |x^*_0(Y) - x^*_i(Y)|
\]

(6)

Table 4. With reference sequence 1 calculated grey relational normalization and deviation sequence $\Delta_{0i}$.

| Exp. No. | Normalization Data | Deviation sequence ($\Delta_{0i}$) |
|----------|--------------------|-----------------------------------|
|          | MRR | SR | MRR | SR |
| 1        | 0.0000 | 0.98658 | 1.0000 | 0.01342 |
| 2        | 0.08454 | 0.98971 | 0.91546 | 0.01029 |
| 3        | 0.16908 | 1.00000 | 0.83092 | 0.00000 |
| 4        | 0.10145 | 0.97855 | 0.89855 | 0.02145 |
| 5        | 0.23671 | 0.98670 | 0.76329 | 0.01330 |
| 6        | 0.37198 | 0.96776 | 0.62802 | 0.03224 |
| 7        | 0.20290 | 0.95835 | 0.79710 | 0.04165 |
| 8        | 0.38889 | 0.95960 | 0.61111 | 0.04040 |
| 9        | 0.57488 | 0.86125 | 0.42512 | 0.13875 |
| 10       | 0.04831 | 0.71509 | 0.95169 | 0.28491 |
| 11       | 0.15700 | 0.92372 | 0.84300 | 0.07628 |
| 12       | 0.26570 | 0.98419 | 0.73430 | 0.01581 |
| 13       | 0.17874 | 0.87153 | 0.82126 | 0.12847 |
| 14       | 0.35266 | 0.96098 | 0.64734 | 0.03902 |
| 15       | 0.52657 | 0.83666 | 0.47343 | 0.16334 |
| 16       | 0.30918 | 0.96224 | 0.69082 | 0.03776 |
| 17       | 0.54831 | 0.98557 | 0.45169 | 0.01443 |
| 18       | 0.78744 | 0.99084 | 0.21256 | 0.00916 |
| 19       | 0.09662 | 0.55576 | 0.90338 | 0.44424 |
| 20       | 0.22947 | 0.90440 | 0.77053 | 0.09560 |
| 21       | 0.36232 | 0.98181 | 0.63768 | 0.01819 |
| 22       | 0.25604 | 0.00000 | 0.74396 | 1.00000 |
| 23       | 0.46860 | 0.71371 | 0.53140 | 0.28629 |
| 24       | 0.68116 | 0.91620 | 0.31884 | 0.08380 |
| 25       | 0.41546 | 0.70932 | 0.58454 | 0.29068 |
| 26       | 0.70773 | 0.60532 | 0.29227 | 0.39468 |
| 27       | 1.00000 | 0.84268 | 0.00000 | 0.15732 |
Table 5. For every experimental value gray Relation coefficient and Overall GRG calculated.

| Exp. No. | Grey relation Coefficient | Gray relational grade | Rank for GRG values |
|----------|---------------------------|-----------------------|---------------------|
|          | MRR                       | SR                    |                     |
| 1        | 0.33333                   | 0.97385               | 0.65359             | 17 |
| 2        | 0.35324                   | 0.97984               | 0.66654             | 13 |
| 3        | 0.37568                   | 1                     | 0.68784             | 7  |
| 4        | 0.35751                   | 0.95886               | 0.65819             | 15 |
| 5        | 0.39579                   | 0.97409               | 0.68494             | 10 |
| 6        | 0.44325                   | 0.93942               | 0.69134             | 6  |
| 7        | 0.38547                   | 0.9231                | 0.65429             | 16 |
| 8        | 0.45                      | 0.92525               | 0.68762             | 8  |
| 9        | 0.54047                   | 0.78278               | 0.66162             | 14 |
| 10       | 0.34443                   | 0.63702               | 0.49072             | 25 |
| 11       | 0.3723                    | 0.86764               | 0.61997             | 19 |
| 12       | 0.40509                   | 0.96935               | 0.68722             | 9  |
| 13       | 0.37843                   | 0.79559               | 0.58701             | 22 |
| 14       | 0.43579                   | 0.92762               | 0.6817              | 11 |
| 15       | 0.51365                   | 0.75376               | 0.6337              | 18 |
| 16       | 0.41988                   | 0.92978               | 0.67483             | 12 |
| 17       | 0.52538                   | 0.97195               | 0.74867             | 3  |
| 18       | 0.70169                   | 0.98201               | 0.84185             | 2  |
| 19       | 0.35628                   | 0.52953               | 0.44291             | 26 |
| 20       | 0.39354                   | 0.83949               | 0.61652             | 20 |
| 21       | 0.43949                   | 0.9649                | 0.70219             | 5  |
| 22       | 0.40194                   | 0.33333               | 0.36764             | 27 |
| 23       | 0.48478                   | 0.6359                | 0.56034             | 23 |
| 24       | 0.61062                   | 0.85645               | 0.73354             | 4  |
| 25       | 0.46102                   | 0.63237               | 0.5467              | 24 |
| 26       | 0.6311                    | 0.55886               | 0.59498             | 21 |
| 27       | 1                         | 0.76066               | 0.88033             | 1  |

The min value of $\Delta_{0i}(Y) = \Delta_{min}$, and max of $\Delta_{0i}(Y) = \Delta_{max}$ [21].

$$\Delta_{0i}(Y) = \Delta_{min} = Min[|x_{0i}(y) - x_{i}^{*}(y)|]$$  \hspace{1cm} (7)

$$\Delta_{0i}(Y) = \Delta_{max} = Max[|x_{0i}(y) - x_{i}^{*}(y)|]$$  \hspace{1cm} (8)

$(\mu)=0.5$, that is identification coefficient it is $0 \leq \mu \leq 1$

$\Delta_{max} = 1$ (MRR)

$\Delta_{min} = 0$ (Surface Roughness)

Grey relational coefficient for experimental values shown in Table 6.
**Step 4** Calculate for Overall GRG., Table 6 show GRG for experimental values[27]. Experiment No. 27 shown the maximize values of GRG.

**Step 5** Mean of GRG calculated.
The average sum of Grey Relational coefficient is mean of GRG.

\[ \gamma(x^*_0, x^*_1) = \gamma_l = \frac{1}{n} \sum_{k=1}^{n} \xi_l(k) \]  

(9)

In this, Number of process parameters = \( n \)

**Step 6** Grey Relational Ranking
The highest values of GRG give a rank 1. Grey relational grades calculate by equation 9. From table 6 it is clear that experiment number 27 has a greatest value of grey relation grade. The greatest value in the S/N curve is examined as optimum parameters. From calculation optimumised parameters has s1f3d3[13, 28].

![Main Effects Plot for Means](image)

**Figure 3** Main effect plot for Mean of Grey relation grade.

| Table 6 Response of Mean for GRG |
|----------------------------------|
| **Level** | **Speed** | **Feed** | **DOC** |
|---------|--------|--------|-------|
| 1-      | 0.6718 | 0.6186 | 0.5640 |
| 2-      | 0.6629 | 0.6220 | 0.6513 |
| 3-      | 0.6050 | 0.6990 | 0.7244 |
| Delta   | 0.0668 | 0.0804 | 0.1604 |
| Rank    | 3      | 2      | 1      |
4. Results and Discussions

It shows significant levels of parameters. Difference of highest and lowest values of GRG is the Significance of parameters. greater significance has a greater difference. By table 7 DOC put the maximum impact on the machining operation and this is followed by feed and speed respectively. Greatest difference means greater significant. Fig.3 shows the mean of GRG. Fig.3 shown that-
- Optimum process parameters are $s_1 f_3 d_1$, i.e. speed 700 in RPM, Feed 0.11 in mm/rev and DOC 1.6 in mm.
- Optimized Surface Roughness is 1.515μm.
- Optimized MRR is 130.884 mm$^3$/sec.
- By increase in speed, GRG decreases up to level 3.
- By Increase of feed, GRG increases up to level 3.
- By Increase of depth of cut, GRG increases up to level 3.

| Table 7. Result of confirmation experiment for GRG. |
|---------------------------------------------------|
| Experiments | Variables | SR   | MRR    |
|--------------|-----------|------|--------|
| Earliest Prediction | $s_1 f_3 d_2$ | 1.663 | 114.255 |
| Experimental  | $s_1 f_3 d_3$ | 1.515 | 130.884 |

5. Conclusions

Grey relation analysis is applied for the optimisation value. From this research work author find optimum value of experimental process parameter, which is feed, speed, and depth of cut with the help of GRG. In this research work we consider the minimum surface roughness and maximum MRR. GRG is the foremost process for calculate the optimum value with minimum time.

Following the experiment results are concluding.
- This lead to maximum MRR and minimum surface Roughness as the DOC increases.
- Speed of level 1, feed of level 3 and DOC of level 3 generate maximum MRR and optimum level of Surface finish.
- Feed has the dominant factor and it has 1$^{st}$ Rank for the optimization.
- Depth of cut (DOC) had the 2$^{nd}$ Rank.
- Speed had a 3$^{rd}$ Rank.

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