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Multi-Objective Process Parameter Optimization for Surface Roughness and Material Removal Rate in Face Milling of Al 6061 T6 Alloy

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Abstract: This study uses Taguchi methodology and Gray Relational Analysis approach to explore the optimization of face milling process parameters for Al 6061 T6 alloy.Surface Roughness (Ra), Material Removal Rate (MRR) has been identified as the objective of performance and productivity.The tests were performed by selecting cutting speed (mm / min), feed rate (mm / rev) and cutting depth (mm) at three settings on the basis of Taguchi's L9 orthogonal series.The grey relational approach was being used to establish a multiobjective relationship between both the parameters of machining and the characteristics of results. To find the optimum values of parameters in the milling operation, the response list and plots are used and found to be Vc2-f1-d3. To order to justify the optimum results, the confirmation tests are performed.The machining process parameters for milling were thus optimized in this research to achieve the combined goals such as low surface roughness and high material removal rate on Aluminum 6061 t6.It was concluded that depth of cut is the most influencing parameter followed by feed rate and cutting velocity.

Keywords : Greyrelation Analysis, Milling, Metal Removal Rate, And Surface Roughness.

I. INTRODUCTION

Milling is most widely used as a straightforward machining method in manufacturing plants and that are used to fit other parts in dies, aircraft, automobile and machine design [1].Due to its ability to create complex structural surfaces with great accuracy and surface finish, end milling is the most significant of different types of milling processes. It can also create a number of configurations with the help of a milling cutter [2]. Small to medium-sized companies produce various key assembly components for international industries and customers [3]. The day-to-day using of steel and aluminum alloy in engineering fields, particularly aluminum alloy materials for precise parts that requires high precision, great quality and often varied requirements of quality [4],[5].

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Heat treated aluminum has certain properties, such as lower thermal conductivity and high ductility, which make them listed under reduced machinability materials which show a great deal of difficulty during machining[6]. This was observed during MACHINING conditions including rate of feed (mm / rev), cutting speed (m / min) and cutting depth(mm) must be systematically defined in order to maximize the economies for manufacturing activities thus increase rate of production. In this article, the study uses Aluminum 6061 T6 alloy to evaluate processing factors and optimization of cutting parameters by use of grey relational analysis based on Taguchi orthogonal array.

II. METHODOLOGY

A. Material

The work piece product chosen for this analysis was Aluminium 6061 T6 alloy, which is used for a wide range of domestic, industrial and commercial purposes such as hardware, bike frames, utensils, electrical fittings and connectors chemical containers, heat exchangers, couplings, machine body parts, automotive and aero industries, structural board s, railings.

B. Taguchi method

Taguchi technique is really a great tool for strong-quality system development. It provides an excellent, efficient and scientific approach in order to optimal designs for performance, quality and reliability. This method is an effective process design that works for optimal efficiency across a wide range of conditions. It involves the use of technically planned experiments to figure out the best model. Taguchi's method to plan experiments in effective and execution for users with minimal statistical knowledge has gained broad attention in the engineering and scientific world.

C. Design of experiments (DOE)

The objective of a experimental design is to influence the outcome by enforcing an alteration of a logical extension expressed in such a parameter termed (independent) predictor.

It is generally expected that the difference in indicator (predictor) will lead to changes in a second variable, therefore the corresponding (dependent) parameter. Design of experiments requires not only the selection of suitable predictors and results, but also the preparation of the test under statistically optimal conditions due to resource constraints.

Different process parameters listed in table1:

Table 1 process parameters

Symbol	Cutting parameters	Level 1	Level 2	Level 3
A	Speed	355	500	710
B	Feed	125	250	500
C	Depth of cut	0.2	0.4	0.6

The design layout based on Taguchi method is shown in table.2

Table 2 Combination of parameters for experimentation

S.NO	Speed	Feed	depth of cut
1	355	125	0.2
2	355	250	0.4
3	355	500	0.6
4	500	125	0.2
5	500	250	0.4
6	500	500	0.6
7	710	125	0.2
8	710	250	0.4
9	710	500	0.6

D. Grey relation analysis

The approach of Grey Relational study was used concurrently to determine the best amount of regulated various factors.

Steps involved in grey relation analysis are:

Step 1: The very first stage of a grey relational analysis was to stabilize the experimentation results by type of output reaction (around 0 to 1). If the initial sequence's target value is infinity, it has a feature of "the-larger-the-better."

$$X_{ij} = \frac{(Y_{ij}) - Min(Y_{ij})}{Max(Y_{ij}) - Min(Y_{ij})} \quad \text{eq.1}$$

If the main sequence's objective value is zero, it will have a character of "the-smaller-the-better."

$$X_{ij} = \frac{Max(Y_{ij}) - (Y_{ij})}{Max(Y_{ij}) - Min(Y_{ij})} \quad \text{eq.2}$$

In the current study, the roughness of the surface is to minimize with ' a-smaller-the better ' feature and the rate of material removal is to maximize by ' a-larger-the better ‘feature.

Here X ij, Y ij for the experiment using jth response are the standardized data and measured data, respectively. Min (Y ij and max (Y ij), respectively, are the smallest and highest Yij values in the responses Larger standardized outcomes mean better performance and the best standardized outcome should be 1.

Step 2: Grey Relation Coefficient (GRC) was measured with below equation.

$$GRC = \frac{\Delta_{min} + \gamma\Delta_{max}}{\Delta_i(k) + \gamma\Delta_{max}} \quad \text{eq. 3}$$

Yij = refers to the sequence of reference.
Xij = indicates the sequence of comparability.
Δi(k) = Yij - Xij
Δmin = lowest of Δi.
Δmax = highest of Δi.
γ = range is [0.0 – 1.0] but 0.5 is widely accepted.

Step 3: The Grey Relational Grade (GRG) is obtained since measuring a GRC as:

$$GRG = \frac{1}{m}\sum_{i=1}^{m} GRC_i \quad \text{eq. 4}$$

Where m is responses number. The Grey relation coefficient as well as the related Grey relation grade was determined for every test. The higher GRG was assigned 1 and the ranks allocated in decreased sequence.

E. Responses to be optimized

Surface Roughness (Ra)

Roughness analysed in its ideal condition by the vertical deviation of a particular surface.

In the current work, Ra function is considered for determining surface roughness.

$$R_a = \frac{1}{n}\sum_{i=1}^{n} |y_i|$$

An arithmetic value of the filtered roughness profile is calculated within the measurement length lm from deviations about the center line.

Material removal rate (MRR)

The rate of removal of material (MRR), is characterized as the amount of material extracted divided by the time of machining.

III. EXPERIMENTATION

These nine successful tests are recorded in Table 3 together with input variables set. For every test three repetitions was conducted and corresponding Ra and MRR are determined. Finally their aggregate was determined and observed results were noted in Table 3.

Table 3. Design of experiments-Taguchi L_9 array

Run no.	Cutting speed (m/min)	Feed (mm/min)	DOC (mm)	Ra (µm)	MRR (g/min)	Time (min)
1	355	125	0.2	0.836	10.638	0.376
2	355	250	0.4	2.732	56.818	0.176
3	355	500	0.6	2.659	69.565	0.115
4	500	125	0.4	0.902	13.404	0.373
5	500	250	0.6	1.495	40	0.175
6	500	500	0.2	2.71	46.296	0.108
7	710	125	0.6	0.604	15.706	0.382
8	710	250	0.2	2.001	23.391	0.171
9	710	500	0.4	2.7	39.215	0.102

To put all of the measured surface roughness and material removal values within 0 to 1 range, the standardization procedure (step 1) was performed. The indicator of better material removal level quality is "higher the better," while surface roughness is "lower the better." Therefore, the standardized surface roughness and rate of material removal values were calculated by eq.2 and eq. 1 respectively. And same has been shown in Table 4 together with their deviations.

Table 4 Normalization values for Ra and MRR

Ra (µm)	**Normalised values (Ra)**	**Deviation values (Ra)**	**MRR (g/min)**	**Normalised values (MRR)**	**Deviation values (MRR)**
0.836	0.890	0.109	10.638	0	1
2.732	0	1	56.818	0.783	0.216
2.659	0.034	0.965	69.565	1	0
0.902	0.859	0.140	13.404	0.046	0.953
1.495	0.851	0.418	40	0.498	0.501
2.71	0.010	0.989	46.296	0.605	0.394
0.604	1	0	15.706	0.086	0.913
2.001	0.343	0.656	23.391	0.216	0.783
2.7	0.015	0.984	39.215	0.484	0.515

In addition, GRC's are calculated using Eq. 3 for both roughness and extraction of material removal. Grey Relation Grade (GRG) is the average surface roughness and material removal rate of GRCs as given in Eq. 4 further ranked in decreasing order to highlight the best combination of input parameters that yield better performance characteristics as shown in Table 5.

Table 5 Grey Relational grade and coefficients values along with rank

Run no.	Grey relation coefficient (Ra)	Greyrelation coefficient(MRR)	Greyrelation grade	Rank
1	0.820	0.333	0.577	3
2	0.333	0.698	0.515	6
3	0.341	1	0.670	2
4	0.781	0.344	0.562	4
5	0.544	0.499	0.521	5
6	0.335	0.558	0.447	7
7	1	0.353	0.676	1
8	0.432	0.389	0.410	8
9	0.336	0.492	0.414	9

IV. RESULTS AND DISCUSSION

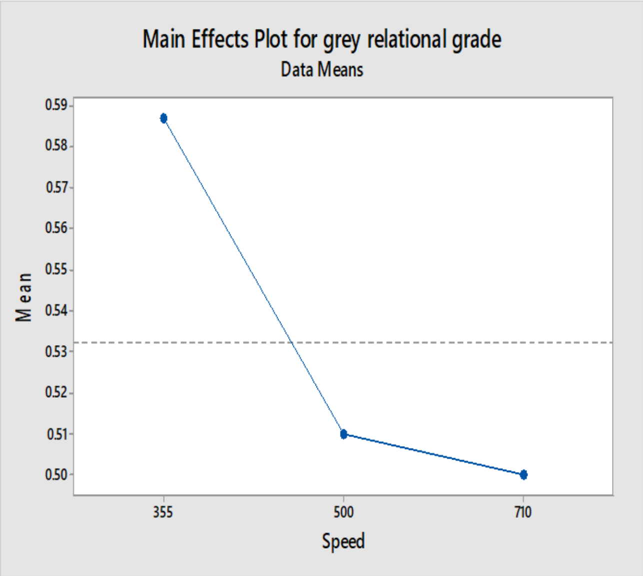
For each experimental test, Table 5 illustrates the grey relational rank. Greater the grey relational grade is the quality of the product. Therefore it is possible to estimate the factors effect on the basis of GRG and their rank and also to assess the optimum level of each controllable variable. The average of GRG for every parameter range is listed in Table 6. The higher GRG value means comparability sequence has a great correlation with the reference series.

Table 6 Response table for Grey Relational Grade

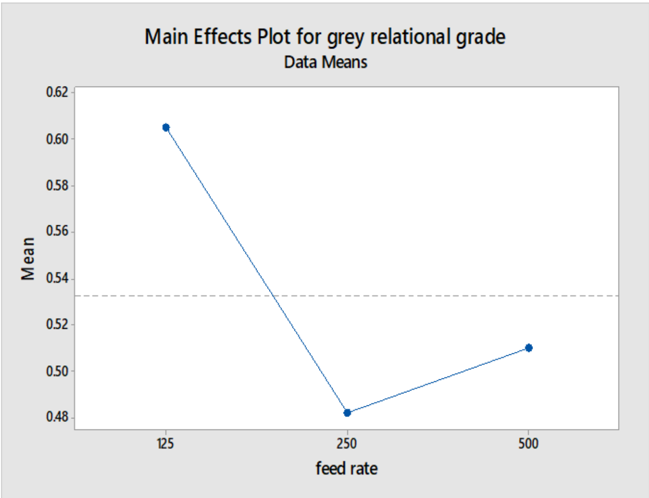
Input factors	**Level 1**	**Level 2**	**Level 3**	**Max-Min**	**Rank**
Cutting speed (Vc)	0.587	0.51	0.5	0.087	3
Feed (f)	0.605	0.482	0.51	0.123	2
Depth of cut (d)	0.478	0.497	0.622	0.478	1

The Major Effects of Plot graphs for GRG were plotted for the stage of processing parameters by using Minitab 15. The larger the grey relational level, the better the multiple characteristics of the results. GRG also decreases from 0.587 to 0.51 in the case of speed as it increases from 355 rpm to 500 rpm and further GRG drops to 0.5 as speed rises from 500 rpm to 710 rpm. In the case of feed, GRG decreases from 0.605 to 0.482 and further increases slightly to 0.51 as feed shifts from 125 mm / min to 250 mm / min and 250 mm / min respectively to 500 mm / min. As depth of cut drops from 0.2 mm to 0.4 mm, GRG improves from 0.478 to 0.497, which rises more significantly to 0.622 as depth of cut rises around 0.4 mm to 0.6 mm. Hence, from Graph 1, 2 and graph 3. we may conclude that the optimal multi-objective optimizations of process parameters are as follows: Cutting speed at level 1 (355 rpm), feed at level 1 (125 mm/min) and depth of cut at level 3 (0.6 mm) i.e. v1-f1-d3.

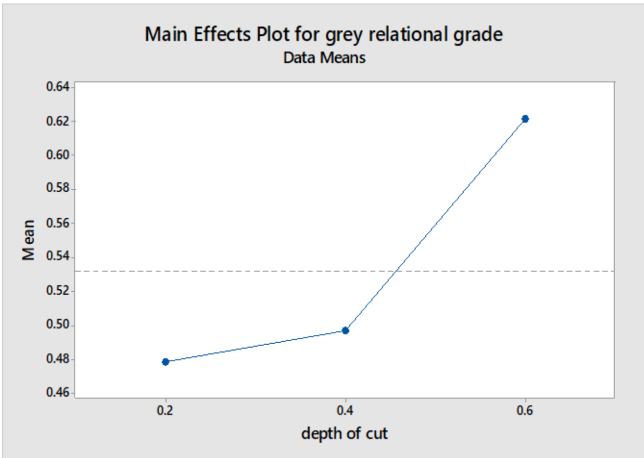
Graph 1: Grey relational grade w.r.t speed



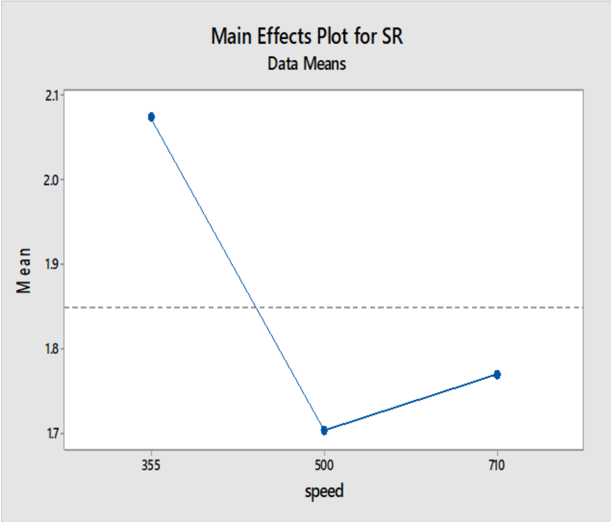
Graph 2: Grey relational grade w.r.t feed rate



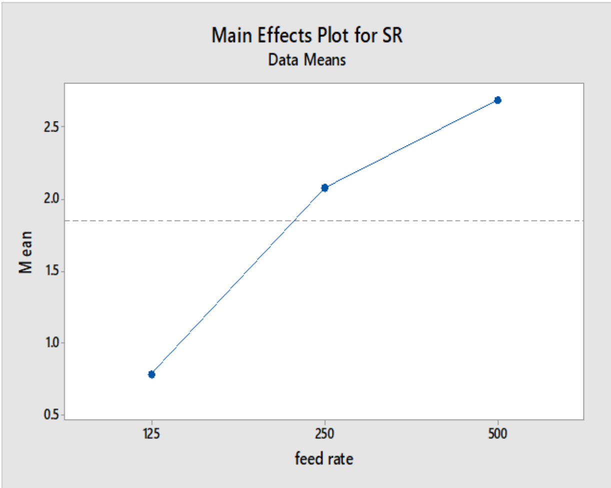
Graph 3: Grey relational grade w.r.t depth of cut



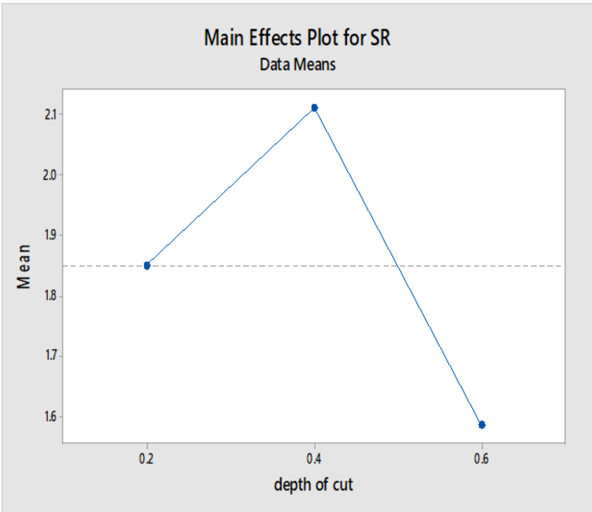
Graph 4: Surface roughness w.r.t speed



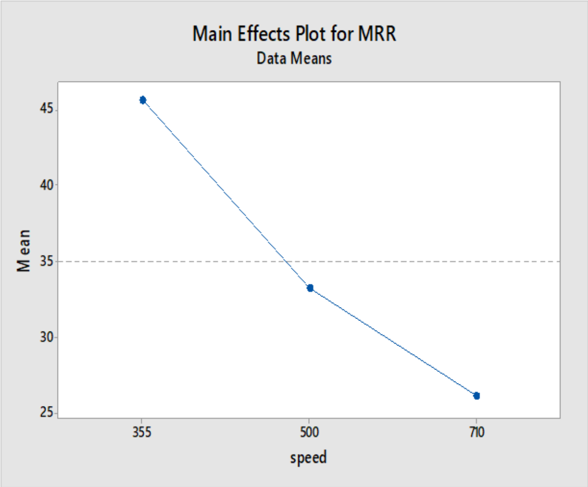
Graph 5: Surface roughness w.r.t feed rate



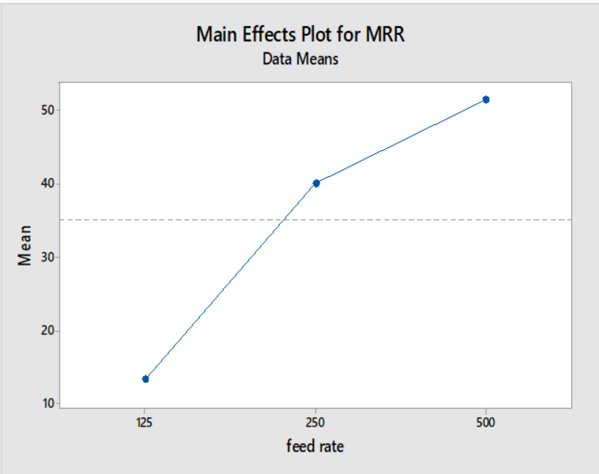
Graph 6: Surface roughness w.r.t depth of cut



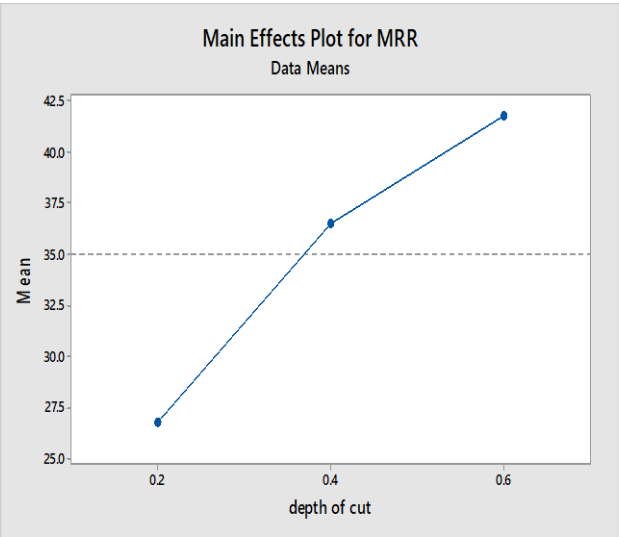
Graph 7: Material removal rate w.r.t speed



Graph 8: Material removal rate w.r.t feed rate



Graph 9: Material removal rate w.r.t depth of cut



Confirmation test

A confirmation experiment was conducted to verify the performance characteristics improvement by using the optimum level of process parameters. Table 7 provides a comparison of the primary experimental run outcome with the experimental run result observed using the optimum cutting parameters in the study. Table 7 shows that the roughness of the surface area decreased by 32.4% after optimization of system parameters and the rate of material removal increased by 0.4%. Therefore it can be concluded that this study can improve the characteristic of Ra performance and MRR.

Table 7: Initial and optimum experimentation values

	Initial Experiment	Optimum Experiment
Setting level	Vc1-f2-d2	Vc1-f1-d3
Ra	2.732	1.846
MRR	56.818	57.057

V. CONCLUSION

The surface roughness value decreased by 32.4 % and the MRR value improved by 0.4 % as when we compare the initial experiment with the optimum test values.

Surface roughness

- Cutting speed, feed rate and cut depth have significant effects on the values of surface roughness.
- Cutting speed affects the roughness of the surface. Increased cutting speed and reduced feed rate results in better surface roughness.
- Depth of cut is found to have effect on surface roughness. Increase in depth of cut value of surface roughness is increase.
- In multi response optimization the optimum parameter combination is meeting at experiment 1 and its parameter value is 0.2 mm depth of cut, 355 rev. cutting speed and 125 mm/min feed rate.

Material removal rate

1• It is possible to achieve better the volume of material extracted when machining is performed at high depth of cut and high feed rate

- Depth of cut has a very large influence in high material removal rate. As the depth of cut value increases, the MRR value increases.

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