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"Gray Relational Based Analysis of Al-6351"

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Abstract: *CNC End Milling Machining is a widely accepted material removal process used to manufacture components with complicated shapes and profiles. The quality of the surface plays a very important role in the performance of milling because good-quality milled surface significantly improves fatigue strength, corrosion resistance, or creep life. The surface generated during milling is affected by different factors such as vibration, spindle run–out, temperature, tool geometry, feed, cross-feed, tool path and other parameters. In the present study, experiments are conducted on aluminium 6351 materials to see the effect of process parameter variation in this respect. An attempt has also been made to obtain Optimum cutting conditions with respect to roughness parameters and Material removal rate .In order to carry out the multi objective optimization Gray relational analysis is used which gives gray relational grade and from the analysis it can be concluded that feed is the most significant parameter for the combined objective function while, speed is the least significant parameter.*
Keywords*-Surface roughness parameter, optimum conditions*

I. Introduction

1.1 Background

CNC End Milling Machining is a widely accepted material removal process used to manufacture components with complicated shapes and profiles. The surface generated during milling is affected by different factors such as vibration, spindle run–out, temperature, tool geometry, feed, cross-feed, tool path and other parameters. The most important interactions, that effect surface roughness of machined surfaces, are between the cutting feed and depth of cut, and between cutting feed and spindle speed. In order to obtain better surface roughness, the proper setting of cutting parameters is crucial before the process takes place. Material removal rate (MRR) is an important control factor of machining operation and the control of machining rate. MRR is a measurement of productivity & it can be expressed by analytical derivation as the product of the width of cut, the feed velocity of milling cutter and depth of cut. The non-linear nature of the machining process has compelled engineers to search for more effective methods to attain optimization. It is therefore imperative to investigate the machinability behavior of different materials by changing the machining parameters to obtain optimal results. This experiment gives the effect of different machining parameters like spindle speed, feed, depth of cut, tool diameter on material removal rate and Surface finish in end milling. This experimental investigation outlines the Gray-Taguchi optimization methodology.

1.2 Problem Statement

The present work focus on optimization of AL-6351 considering the various process parameters the objectives of the current is as follows;

1) To find the optimum values for the input parameters like speed (N), feed (f) ,depth of cut(d),tool diameter and its effect on the surface finish for achieving the minimum surface roughness**.** Objective function for first objective is to Minimize Surface roughness (R_a) subjected to minimum and maximum range of input parameters like speed (N), feed (f), depth of cut (d), and tool diameter.

2) To select the order of input parameters to get the maximum MRR. The Objective function is to; Maximize Material removal rate (MRR) subjected to minimum and maximum range of input parameters like speed (N), feed (f), and depth of cut (d) & tool diameter.

1.3 Scope

Surface roughness and MRR are very important which rely on many parameters, its need of hour to have the experimental investigation for optimum values by satisfying the desired constraints to achieve particular objective.

II. Literature Review

Joshi et al. [1] investigated the SR response on CNC milling by Taguchi technique. Surface finish is analyzed, which shows the percentage contribution of each influencing factor. Anish Nair & P Govindan [2] conduct the study on application of Principal Component analysis (PCA) coupled with Taguchi method to solve correlated multi-attribute optimization of CNC end milling operation.PCA has been proposed to eliminate correlation between the responses and to estimate uncorrelated quality indices called principal components. Shahzad Ahmad et al. [3] studied the machining parameters like depth of cut, cutting speed, feed rate and tool diameter are optimized with multiple performance characteristics, and concluded that the S/N ratio with Taguchi's parameter design is a simple, systematic, reliable and more efficient tool for optimizing multiple performance characteristics of CNC milling process parameters. J.Pradeep Kumar & K.Thirumurugan [4] had studied The end milling of titanium alloys, for the investigation of the optimum parameters that could produce significant good surface roughness whereby reducing tooling cost and concluded that The significant factors for the surface roughness in milling CP Ti Grade 2 were the spindle speed and the tool grade, with contribution of 30.347 and 29.933 respectively. Reddy S [5] had conducted the study to deals with optimization of surface roughness and delamination damage on GFRP material during end milling using grey- based taguchi method. From the results of ANOVA, it was concluded that cutting speed and DOC are the most significant factors. PR.Periyanan et al [6] had carried out experiment to focus the taguchi technique for the optimization in micro-end milling operation to achieve maximum metal removal rate & result shows that the optimal combination as medium cutting speed, high feed rate and high depth of cut. Piyush pandey et al [7] conducted experiments to perform the parametric optimization of CNC end milling machine tool in varying condition. Results showed that cutting speed and feed are the powerful control parameters for the material removal rate and depth of cut as powerful factors for controlling the surface finish of Mild Steel. K. Barman, P. Sahoo [8] had conducted an experimental study of fractal dimension characteristics of surface profile produced in CNC milling and optimization of machining parameters based on Taguchi method. It is also observed with increase in spindle speed the fractal dimension increases. S.B.Chawale et al [9] had conducted to study experimentally the influence of depth of cut, cutting speed, and feed and work piece material type on cutter temperature during milling process. It was concluded that, the cutting speed is most contributory factor, work material is second important factor and Feed rate is third important factor.Abhishek Dubey et al [10] had conducted study for the multiple response optimization of end milling parameter using grey based taguchi method. The feed rate was identified as the most influential process parameter on surface roughness.

III. Experimental Methodology

3.1 Design of Experiments

Design of experiments (DOE) is a powerful tool that can be used in a variety of experimental situations. DOE techniques enable designers to determine simultaneously the individual and interactive effects of many factors that could affect the output results in any design. To achieve a thorough cut it was required that the combinations of the process variables give the jet enough energy to penetrate through the specimens. In the present study four process parameters were selected as control factors. The parameters and levels were selected based on the actual Machining setup and literature review of some studies that had been documented on end milling. But considering all practical limitation with actual machining centre Speed, Feed, Depth of cut and tool diameter are selected for experimentation. For designing the experiment "Minitab 17 software" is used. Following are the details of experiment design.

Number of Experimental factors:
Number of blocks: 1
Number of responses: 2
Number of runs: 9, including 9 slots over the entire length of work piece
Error degrees of freedom: 8

3.2. Machine Specifications

The technical specifications are of which are as follows.

Table 3.1- Machine details

Make and Model	MAKINO-S 56
Controller	Fanuc
Technical Specifications	
Table size	1000*500mm
Spindle RPM	13000
Maximum Work piece	890*500*450
Maximum Payload	1100lbs
ATC Capacity	20

3.3 Material

For the present work the material use are block of Aluminum 6351 in the dimensions 160mm × 100 mm × 32 mm. The physical properties of the material are as follows.

Table 3.2.Physical properties of materials

Physical Properties	Al6361
Density	2710Kg/m3
Hardness(Brinell)	95
Hardness(Knoop)	120
Hardness(Rockwell B)	40
Ultimate Tensile strength	250MPA
Yield strength	207MPA

Table 3.3.The chemical compositions of the material AL-6351

Component	Composition
Fe	0.12
Al	95.51
Mn	0.52
Si	0.8
Cu	0.051
Mg	0.75
Ti	0.017
Zr	0.003
Pb	0.012
Ca	0.051
Sn	0.004

3.4. CUTTING TOOL

In this experiment the HSS end mill cutter of varying diameter like 8mm, 10mm & 12mm is used to make the grove of 12mm in the work piece for given speed, feed & depth of cut.

3.5. SELECTION OF ORTHOGONAL ARRAY

Orthogonal arrays are special standard experimental design that requires only a small number of experimental trials to find the main factor effects on output. The minimum number of experiments to be conducted shall be fixed which is given by: NTaguchi = 1+ NV (L – 1) where, N Taguchi = Number of experiments to be conducted, NV = Number of variables = Number of levels. Four machining parameters are considered as controlling factors namely, cutting speed, depth of cut, feed rate, Tool diameter and each parameter has three levels – namely low, medium and high, denoted by 1,2 and 3, respectively. Standard OAs available are L4, L8, L9, L12, L16, L18, L27, etc once the orthogonal array is selected, the experiments are selected as per the level combinations. The number of DOF for orthogonal array should be greater than or equal to number of DOF required.

i) Number of control factors = 4
ii) Number of levels for each control factors = 3
iii) Total degrees of freedom of factors = 4x(3-1)=8
iv)Number of experiments to be conducted =9

Based on these values and the required minimum number of experiments to be conducted 9, the nearest Orthogonal Array fulfilling this condition is L9 (3^4)[11]

IV. Grey Based Analysis For Combine Objective

GRA was proposed by Deng in 1989 as cited in is widely used for measuring the degree of relationship between sequences by grey relational grade. Grey relational analysis is applied by several researchers to optimize control parameters having multi-responses through grey relational grade, steps are as follows;

1. Identify the performance characteristics and cutting parameters to be evaluated.
2. Determine the number of levels for the process parameters.
3. Select the appropriate orthogonal array and assign the cutting parameters to the orthogonal array.
4. Conduct the experiments based on the arrangement of the orthogonal array.
5. Normalize the experiment results of cutting force, tool life and surface roughness.
6. Perform the grey relational generating and calculate the grey relational coefficient.
7. Calculate the grey relational grade by averaging the grey relational coefficient.
8. Analyze the experimental results using the grey relational grade and statistical ANOVA.
9. Select the optimal levels of cutting parameters.
10. Verify the optimal cutting parameters through the confirmation experiment [12].

4.1 Data Pre-Processing.

In grey relational analysis, the data pre-processing is the first step performed to normalize the random grey data with different measurement units to transform them to dimensionless parameters. Thus, data pre-processing converts the original sequences to a set of comparable sequences. Different methods are employed to pre-process grey data depending upon the quality characteristics of the original data. The original reference sequence and pre-processed data (comparability sequence) are represented by $xx0\ (0)(kk)$ and $xxii\ (0)(kk)$, i =1,2,….,m; k =1,2,.....,n respectively, where m is the number of experiments and n is the total number of observations of data. Depending upon the quality characteristics, the three main categories for normalizing the original sequence are identified as follows:

If the original sequence data has quality characteristic as 'larger-the-better' then the original data is pre-processed as 'larger-the-best:

$$xi(k) = \frac{\text{yi(k)} - \min\ \text{yi(k)}}{\max \text{yi(k)} - \min\ \text{yi(k)}}$$

If the original data has the quality characteristic as 'smaller the better', then original data is pre-processed as 'smaller-the best':

$$xi(k) = \frac{\max\ \text{yi(k)} - \ \text{yi(k)}}{\max \text{yi(k)} - \min\ \text{yi(k)}}$$

Xi=Compatibility sequence

4.2. SAMPLE CALCULATION OF COMPATIBILITY SEQUENCE FOR ROUGHNESS VALUE

$$xi(k) = \frac{\text{Max CT} - \text{First Value of CT}}{\text{Max CT} - \text{Min CT}}$$

$$xi(k) = \frac{16.6881 - 7.7867}{16.6881 - 6.3661} xi(k) = 0.8622$$

Table 4.1 Normalized S/N data (Grey relational generation)

Sr no	S/N Ra	S/N MRR	Xi	Δ Xi	Xi MRR	ΔMRR
1	8.93	26.36	0.75	0.25	0	1
2	7.78	33.13	0.86	0.137	0.7467	0.2533
3	8.95	35.42	0.74	0.25	1	0
4	8.61	32.73	0.78	0.217	0.7036	0.2964
5	11.38	29.67	0.51	0.487	0.3648	0.6352
6	12.70	33.25	0.38	0.615	0.7607	0.2393
7	16.67	29.48	0	1	0.3444	0.6556
8	11.81	33.39	0.47	0.528	0.7754	0.2246
9	6.366	35.33	1	0	0.9906	0.0094

Similarly all values of compatibility sequence for surface roughness and material removal rate can be Calculated All values are show in Table 4.1.

Where xi (k) is the value after the grey relational generation, min yi (k) is the smallest value ofyi (k) for the k^{th} response, and max yi (k) is the largest value of yi (k) for the k^{th} response. An ideal sequence is x0(k) (k=1, 2) for two responses. The definition of the grey relational grade in the grey relational between the twenty-seven sequences (x0(k) and *xi* (k), i=1, 2 . . . 27; k=1, 2). The grey relational coefficient *ξi*(k) can be calculated as:

4.3 Sample Calculation Of Grey Relation Coefficient For Roughness Value

$$\xi i(k) = \frac{\min\Delta + \theta * \max\Delta}{\Delta i(k) + \theta * \max\Delta}$$

ξi(k) =The grey relational coefficient

θ is the distinguishing coefficient which is taken as 0.5

$$\xi i(k) = \frac{0 + (0.5 * 1)}{0.1378 + (0.5 * 1)}$$

***ξi*(k) = for second value = 0.7839**

Similarly, all values of grey relation coefficient for roughness and material removal rate are calculated and tabulated in the table given below.

4.4 Sample Calculation Of Grey Relation Grade For Roughness Value And Mrr.

After averaging the grey relational coefficients, the grey relational grade γi can be computed as,

$$\boldsymbol{Yi} = \frac{\mathbf{1}}{\boldsymbol{n}}\sum_{k=1}^{n} = \xi i[k]$$

$$\boldsymbol{Yi} = \frac{\mathbf{1}}{\mathbf{2}}(0.7839 + 0.6637)$$

First reading of grey relation grade is, **Yi = 0.7238**

Similarly all values of grey relation grade of nine experiments are carried out and tabulated in table given below

Yi =grey relational grade

Where n = number of process responses. The higher value of grey relational grade corresponds to intense relational degree between the reference sequence x0 (k) and the given sequence xi (k). The reference sequence x0 (k) represents the best process sequence. Therefore, higher grey relational grade means that the corresponding parameter combination is closer to the optimal**.**

Table 4.2: Grey Relation Grade, coefficient and Order

Experiment no	Ra	MRR	GRC For Ra	GRC For MRR	GRG	Gray order
1	0.3575	20.0764	0.6666	0.3333	0.49995	7
2	0.408	45.3319	0.7839	0.6637	0.7238	3
3	0.3565	59.8045	0.6655	1	0.83275	2
4	0.371	43.2495	0.6964	0.6278	0.6621	4
5	0.2695	30.4462	0.5065	0.4404	0.47345	8
6	0.2315	46.0105	0.4483	0.6763	0.5623	6
7	0.15	29.8065	0.3333	0.4326	0.38295	9
8	0.2565	46.7199	0.4888	0.69	0.5894	5
9	0.4805	58.4783	1	0.9815	0.99075	1

V. Analysis Of The Combined Objective By Using Taguchi

Table 4.3: Response Table for Taguchi analysis

Sr	Speed	Feed	DOC	Diameter	GRG	SNRA1
1	2000	300	1	8	0.49995	-6.02147
2	2000	500	1.25	10	0.7238	-2.80763
3	2000	700	1.5	12	0.83275	-1.58971
4	3000	300	1.25	12	0.6621	-3.58153
5	3000	500	1.5	8	0.47345	-6.49452
6	3000	700	1	10	0.5623	-5.00064
7	4000	300	1.5	10	0.38295	-8.33716
8	4000	500	1	12	0.5894	-4.5918
9	4000	700	1.25	8	0.99075	-0.08072

5.1 Main Effect Plot For Combine Objective

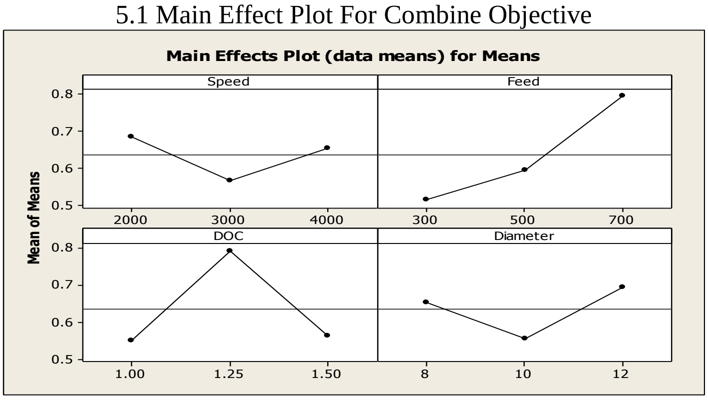

Fig 4.1Fig: Main effect plot for Mean

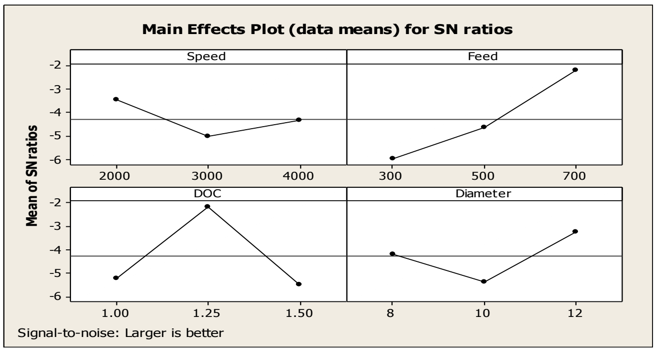

Fig 4.2 Fig: Main effect plot for surface roughness

Table 4.4.Response table for S/N ratio for combined Objective

Level	Speed	Feed	DOC	Diameter
1	-3.473	-5.980	-5.205	-4.199
2	-5.026	-4.631	-2.157	-5.382
3	-4.337	-2.224	-5.474	-3.254
Delta	1.553	3.756	3.317	2.127
Rank	4	1	2	3

Table 4.5.Response table for Mean

Level	Speed	Feed	DOC	Diameter
1	0.6855	0.5150	0.5506	0.6547
2	0.5660	0.5956	0.7922	0.5564
3	0.6544	0.7953	0.5631	0.6948
Delta	0.1195	0.2803	0.2417	0.1384
Rank	4	1	3	2

VI. Conclusion

From this experiment it is concluded that-
i) The optimum levels for the optimization are (3 3 2 3) and the optimum parameter are- 4000 700 1.25 12.
ii) The significant parameter are Feed>Diameter>DOC>Speed.
iii) Gray Relational analysis method is successfully applied which gives the gray relational grade.

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