Experimental Investigation of AL-6351 by using Gray Taguchi Methodology

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Abstract - CNC End Milling Machining is frequently used material removal process to manufacture components with complicated shapes and profiles. The quality of the surface which plays a very vital role in the performance depends on many factors such as vibration, spindle run–out, temperature, tool geometry, feed, cross-feed, tool path. In the present study, experiments are conducted on aluminium 6351 materials to see the effect of process parameter variation. An attempt has also been made to obtain Optimum cutting conditions with respect to roughness parameters and Material removal rate. Minitab 17 is used to obtain the optimum parameters considering the single objective function of surface roughness for Ra & Rz and MRR respectively In order to carry out the multi objective optimization Gray relational analysis is used which gives gray relational grade for combined objective function also gives the values for optimum parameters. From the analysis it can be concluded that Feed is the most significant parameter for the combined objective function while, Tool diameter is the least significant parameter.

Keywords-Surface roughness parameter, optimum conditions

I.INTRODUCTION

Milling is defined as the process of cutting away material by feeding a work piece past a rotating multiple tooth cutter. The cutting action of the many teeth around the milling cutter provides a fast method of machining. The machined surface may be flat, angular, or curved. The surface may also be milled to any combination of shapes.CNC End Milling Machining is a widely accepted material removal process used to manufacture components with complicated shapes. 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, depth of cut, and spindle speed. Thus, 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 necessary to investigate the machinability behavior of material by changing the machining parameters to obtain optimal results. This experiment gives the effect of different machining parameters spindle speed, feed, depth of cut, tool diameter on material removal rate and Surface removal rate in end milling. This experimental investigation outlines the Gray-Taguchi optimization methodology [1,2]

1.1. Problem Statement

The present work focus on experimentation investigation of AL-6351 considering the various process parameters, the main Objectives are,

1)To select 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**.** i.e. single objective optimization of Surface roughness For Ra & Rz by Taguchi Methodology.

2) To select the order of input parameters to get the maximum MRR by Taguchi Methodology.

3) To carryout multi objective optimization by using Gray Relational Analysis

1.2 Scope

Surface roughness and MRR are very important which depend 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.EXPERIMENTAL METHODOLOGY

2.1Design of Experiments

Design of experiments (DOE) is a very powerful tool that can be used in a variety of experimental situations. In the present study four process parameters are selected as control factors. The parameters and levels are selected based on the actual Machining setup and literature review of some studies that had been carried on end milling. Considering all practical limitation with actual machining centre ,Speed, Feed, Depth of cut and tool diameter are selected for experimentation. "Minitab 17 software" is used for designing the experiment. The details of experiment design are as follows [3,4]

Number of Experimental factors:

Number of blocks: 1

Number of responses: 2

Number of run s: 9, including 9 slots over the entire length of work piece

degrees of freedom: 8

2.2. Machine Specifications

The technical specifications of machining centre are as follows.

Table 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

2.3. Material

For the present work block of Aluminum 6351 in the dimensions 160mm × 100 mm × 32 mm is used. The physical & chemical properties of which are as follows

Table 2.Physical properties of materials

Physical Properties	Al 6361
Density	2710Kg/m3
Hardness(Brinell)	95
Hardness(Knoop)	120
Hardness(Rockwell B)	40
Ultimate Tensile strength	250MPA
Yield strength	207MPA

Table 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

2.4 Cutting Tool

HSS end mill cutter of 8mm, 10mm & 12mm diameter are use to make the grove of 12mm in the work piece for given speed, feed & depth of cut for the present work.

2.5 Selection of Orthogonal Array

For selecting an orthogonal array, 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, feed rate, depth of cut, 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.

i) Number of control factors = 4

ii) Number of levels for each control factors = 3

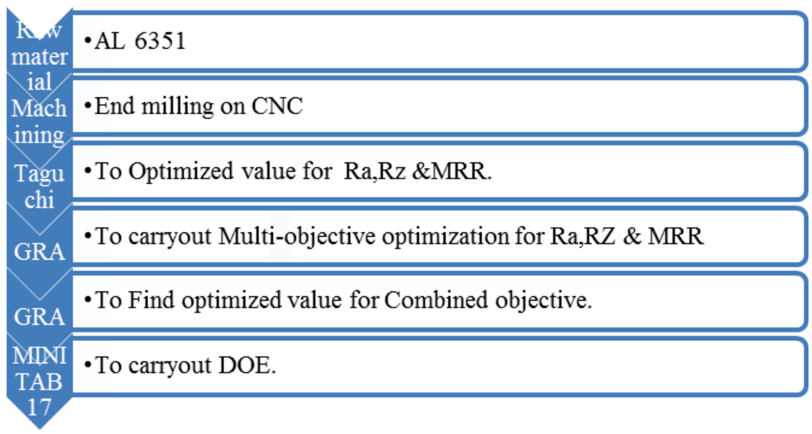
iii) Total degrees of freedom of factors = 4x(3-1)=8

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]

2.5 Proposed Workflow

For the optimization AL 6351 to achieve the desired objective of minimum surface roughness and maximum material removal rate, the method of the design of experiment & GRA is identified and the proposed algorithm as follows



III.TAGUCHI APPROACH

Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments. The experimental results are then transformed into signal-to-noise (S/N) ratio. Taguchi recommends the use of the S/N ratio to measure the quality characteristics deviating from the desired values. Usually there are three categories of quality characteristics deviating from the desired values i.e. the lower the better, the higher the better and the nominal is the better. The S/N ratio for each level of process parameter is computed based on S/N ratio analysis. A greater S/N ratio corresponds to the better quality characteristics.[19]

The inputs to the parameter design by Taguchi method includes following steps

(1) Identification of quality characteristics and selection of design parameters to be evaluated,

(2) Determination of the number of levels for the design parameters and possible interactions between the design parameters.

(3) Selection of the appropriate orthogonal array and assignment of design parameters to the orthogonal array,

(4) Conducting the experiments based on the arrangement of the orthogonal array,

(5) Analysis of the experimental results using the S/N and ANOVA analysis,

(6) Selection of the optimal levels of design parameters and

(7) Verification of the optimal design parameters through the confirmation experiment.

After taking all reading of surface roughness and material removal rate(MRR) all values are put in the following table which is use for further analysis purpose.

Table 4-Experimental Values

Sr no	Speed (rpm)	Feed (mm/min)	DOC (mm)	Diameter (mm)	Ra (Microns)	Rz (Microns)	MRR (mm^3/s)
1	2000	300	1	8	0.3575	1.5875	20.076
2	2000	500	1.25	10	0.408	1.9825	45.331
3	2000	700	1.5	12	0.3565	1.5875	59.804
4	3000	300	1.25	12	0.371	2.045	43.249
5	3000	500	1.5	8	0.2695	1.416	30.446
6	3000	700	1	10	0.2315	1.368	46.010
7	4000	300	1.5	10	0.15	0.9105	29.806
8	4000	500	1	12	0.2565	1.3365	46.719
9	4000	700	1.25	8	0.4805	2.523	58.478

3.1 Signal to Noise Ratio (S/N)

Parameter design study involves control and noise factors. The measure of interaction between these factors with regard to robustness is signal-to–noise (S/N) ratio. The signal to noise ratio (S/N ratio) was used to measure the sensitivity of the quality characteristic being investigated in a controlled manner. In Taguchi method, the term 'signal' represents the desirable effect (mean) for the output characteristic and the term 'noise' represents the undesirable effect (signal disturbance, S.D) for the output characteristic which influence the outcome due to external factors namely noise factors. The S/N ratio can be defined as[5]

S/N ratio, $\eta = -10 \log (MSD)$ (1)

where, MSD :mean-square deviation for the output characteristic. The aim of any experiment is always to determine the highest possible S/N ratio for the result. A high value of S/N implies that the signal is much higher than the random effects of the noise factors or minimum variance. As mentioned earlier, there are three categories of quality characteristics, i.e. the-lower-the-better, the higher-the-better, and the-nominal-the-better. To obtain optimal blanking performance, the-lower-the-better quality characteristic for burr height must be taken. The mean-square deviation (M.S.D.) for the-higher -the-better quality characteristic can be expressed as

$$MSD = \frac{1}{n}\sum_{i=1}^{n} y_i^{\,2} \quad (2)$$

Where, n = number of repetitions or observations & yi = the observed data.

3.2 Deciding optimum level for the individual Objective i.e Optimization of single objective

Table 5-Analysis of Ra

Speed	Feed	DOC	Diameter	Ra	SNRA
2000	300	1	8	0.3575	8.928291
2000	500	1.25	10	0.408	7.780123
2000	700	1.5	12	0.3565	8.931142
3000	300	1.25	12	0.371	8.504053
3000	500	1.5	8	0.2695	11.36377
3000	700	1	10	0.2315	12.69828
4000	300	1.5	10	0.15	16.42275
4000	500	1	12	0.2565	11.8044
4000	700	1.25	8	0.4805	6.361014

Main Effect Plots

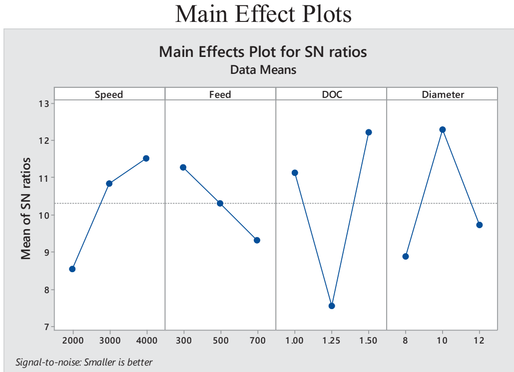


Fig-1 S/N Effect plots

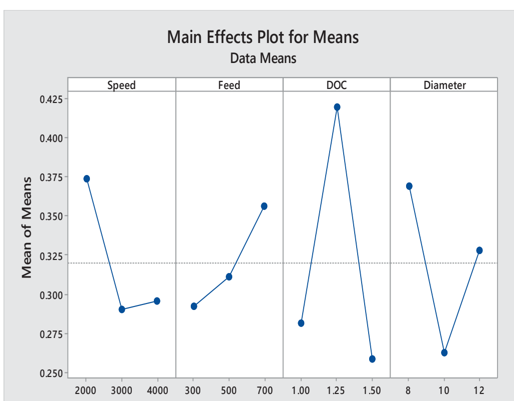


Fig 2-Mean Effect Plots

Table 6.Response table for S/N Ratio surface Roughness

Level	Speed	Feed	DOC	Diameter
1	8.547	11.285	11.144	8.884
2	10.855	10.316	7.548	12.300
3	11.529	9.330	12.239	9.747
Delta	2.983	1.955	4.691	3.416
Rank	3	4	1	2

Table 7. Response table for Mean.

Level	Speed	Feed	DOC	Diameter
1	0.3740	0.2928	0.2818	0.3692
2	0.2907	0.3113	0.4198	0.2632
3	0.2957	0.3562	0.2587	0.3280
Delta	0.0833	0.0633	0.1612	0.1060
Rank	3	4	1	2

Findings based on From the Graph and the S/N ratio table -

i) Optimum Level for the optimization are 3 1 3 2 with the parameters as 4000 300 1.5 10

ii) The Significant parameter are DOC>Tool Diameter>Speed>Feed

Table 8.Rz analysis

Speed	Feed	DOC	Diameter	Rz	S/N
2000	300	1	8	1.587	-4.29
2000	500	1.25	10	1.982	-5.94
2000	700	1.5	12	1.587	-4.29
3000	300	1.25	12	2.045	-6.38
3000	500	1.5	8	1.416	-3.02
3000	700	1	10	1.368	-2.75
4000	300	1.5	10	0.910	-0.78
4000	500	1	12	1.336	-2.52
4000	700	1.25	8	2.523	-8.04

Main Effect Plots for Rz

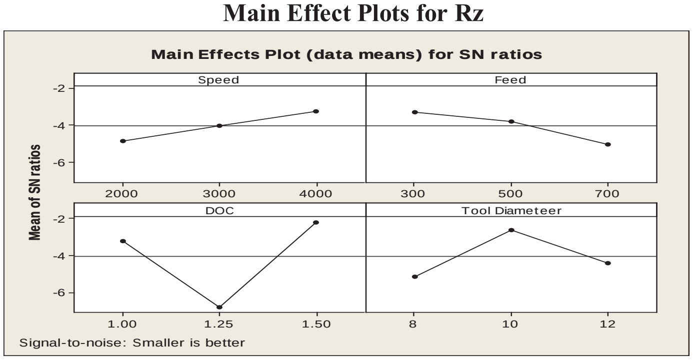


Fig3: Main effect plot for S/N

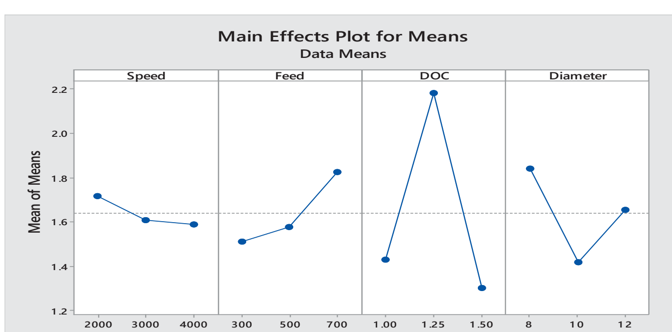


Fig 4: Main effect plot for Means

Table 9.Response table for S/N ratio

Level	Speed	Feed	DOC	Diameter
1	-4.847	-3.299	-3.190	-5.125
2	-4.056	-3.832	-6.794	-2.635
3	-3.260	-5.033	-2.180	-4.404
Delta	1.586	1.734	4.615	2.489
Rank	4	3	1	2

Table 10.Response table for mean.

Level	Speed	Feed	DOC	Diameter
1	1.719	1.514	1.431	1.842
2	1.610	1.578	2.184	1.420
3	1.590	1.826	1.305	1.656
Delta	0.129	0.312	0.879	0.422
Rank	4	3	1	2

From the graphs and plots following conclusions can be drawn-

i)The optimum levels for the optimization are (3 1 3 2) and the optimum parameter are- 4000 300 1.5 10.

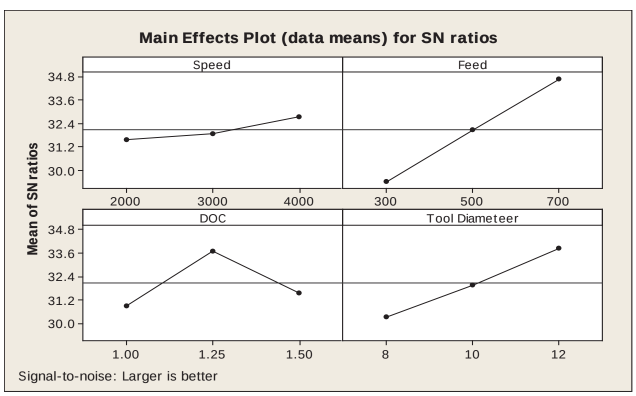
ii) The significant parameter are DOC>Diameter>Feed>Speed.

Table 11.MRR Analysis

Speed	Feed	DOC	Diameter	MRR	S/NMRR
2000	300	1	8	20.076	26.053
2000	500	1.25	10	45.331	33.128
2000	700	1.5	12	59.804	35.534
3000	300	1.25	12	43.249	32.719
3000	500	1.5	8	30.446	29.670
3000	700	1	10	46.010	33.257
4000	300	1.5	10	29.806	29.486
4000	500	1	12	46.719	33.39
4000	700	1.25	8	58.478	35.339

Main Effect plots for MRR.

Fig 5 : Main effect plot for MRR



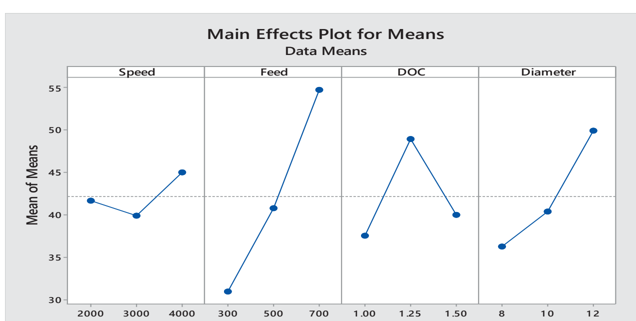


Fig 6: Main effect plot for means

Table 12.Response table for S/N ratio

Level	Speed	Feed	DOC	Diameter
1	-4.673	-4.174	-4.808	-4.207
2	-5.627	-5.353	-5.472	-5.118
3	-4.841	-5.612	-4.859	-5.815
Delta	0.954	1.438	0.664	1.608
Rank	3	2	4	1

Table 13.Response table for mean

Level	Speed	Feed	DOC	Diameter
1	41.74	31.04	37.60	36.33
2	39.90	40.83	49.02	40.38
3	45.00	54.76	40.02	49.92
Delta	5.10	23.72	11.42	13.59
Rank	4	1	3	2

From the graphs and plots following conclusions can be drawn-

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.

IV.GREY BASED TAGUCHI ANALYSIS FOR COMBINE OBJECTIVE

Grey relational analysis 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:

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.**[5,10]**

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:

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

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

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

Xi=Compatibility sequence

4.2. Sample Calculation of Compatibility Sequence For Roughness Value

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

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

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

Table 14 Normalized S/N data (Grey relational generation)

Sr.No	S/N Ra	S/N Rz	S/N MRR	Xi Ra	Xi Rz	Xi MRR	Δ Ra	Δ Rz	Δ MRR
1	8.93	4.01427	26.36	0.75	0.55	0	0.25	0.45	1
2	7.78	5.94426	33.13	0.86	0.28988	0.7467	0.137	0.71012	0.2533
3	8.95	4.01427	35.42	0.74	0.55	1	0.25	0.45	0
4	8.61	6.21386	32.73	0.78	0.25256	0.7036	0.217	0.74743	0.2964
5	11.38	3.02126	29.67	0.5129	0.69451	0.3648	0.4871	0.30549	0.6352
6	12.708	2.72172	33.2571	0.3849	0.73597	0.7607	0.6151	0.26403	0.2393
7	16.678	0.8144	29.486219	0	1	0.3444	1	0	0.6556
8	11.818	2.51937	33.390	0.47	0.76398	0.7754	0.5288	0.23602	0.2246
9	6.366	8.03834	35.339	1	0	0.9907	0	1	0.0093

Where xi (k) is the value after the grey relational generation, min yi (k) is the smallest value of yi (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,

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

$$Yi = \frac{1}{3}(0.3333 + 0.9815 + 1)$$

For second reading of grey relation grade is,**Yi = 0.7716**

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 **[10]**

Table 15: Grey Relation Grade, coefficient and Order

GRC For Ra	GRC FOR Rz	GRC For MRR	GRG	GRAR ORDER
0.666	0.5263	0.3333	0.508533	9
0.783	0.4131	0.6637	0.619933	3
0.665	0.5363	1	0.733767	2
0.696	0.40082	0.6278	0.574873	7
0.506	0.62074	0.4404	0.52238	8
0.448	0.65442	0.6763	0.592907	5
0.333	1	0.4326	0.588533	6
0.488	0.67972	0.69	0.61924	4
1	0.33333	0.9815	0.77161	1

V. ANALYSIS OF THE COMBINED OBJECTIVE BY USING TAGUCHI

Table 16: Response Table for Taguchi analysis

Sr	Speed	Feed	DOC	Dia.	GRG	SN
1	2000	300	1	8	0.508533	-5.87362
2	2000	500	1.25	10	0.619933	-4.1531
3	2000	700	1.5	12	0.733767	-2.68884
4	3000	300	1.25	12	0.574873	-4.80856
5	3000	500	1.5	8	0.52238	-5.64027
6	3000	700	1	10	0.592907	-4.54027
7	4000	300	1.5	10	0.588533	-4.60458
8	4000	500	1	12	0.61924	-4.16282
9	4000	700	1.25	8	0.77161	-2.25204

MAIN EFFECT PLOT FOR COMBINE OBJECTIVE

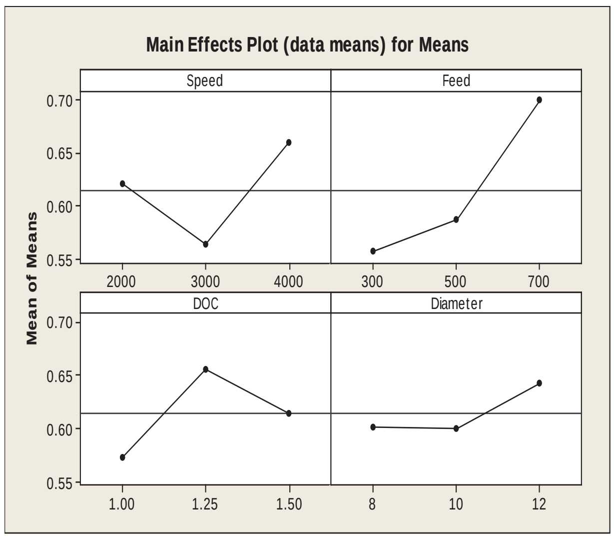


Fig 7: Main effect plot for Mean

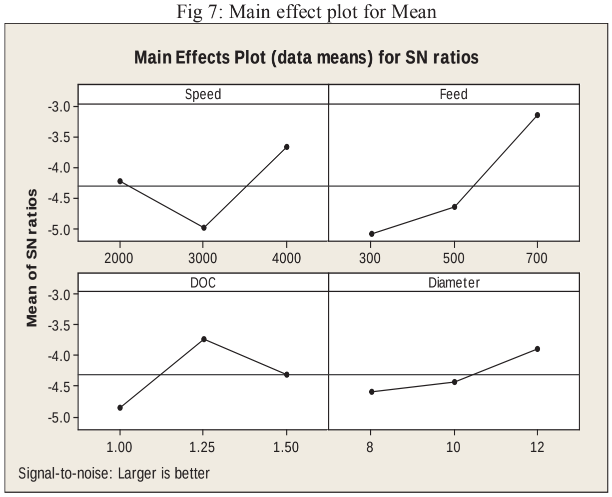


Fig 8: Main effect plot for surface roughness

Table 17.Response table for S/N ratio for combined Objective

Level	Speed	Feed	DOC	Diameter
1	-4.239	-5.096	-4.859	-4.589
2	-4.996	-4.652	-3.738	-4.433
3	-3.673	-3.160	-4.311	-3.887
Delta	1.323	1.935	1.121	0.702
Rank	2	1	3	4

Table 18.Response table for Mean

Level	Speed	Feed	DOC	Diameter
1	0.6207	0.5573	0.5736	0.6008
2	0.5634	0.5872	0.6555	0.6005
3	0.6598	0.6994	0.6149	0.6426
Delta	0.0964	0.1421	0.0819	0.0422
Rank	2	1	3	4

From the graphs and plots following conclusions can be drawn-
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>Speed>DOC>Diameter.

VI. CONCLUSION

From this experiment it is concluded that-
i) Optimum Level for the single objective optimization for surface roughness (Ra) are -3 1 3 2 with the parameters as 4000 300 1.5 10 & The Significant parameter are DOC>Tool Diameter>Speed>Feed.
ii) The optimum levels for the optimization are (31 3 2) and the optimum parameter are- 4000 300 1.5 10.The significant parameter are DOC>Diameter>Feed>Speed.
iii) Optimum Level for the single objective optimization for MRR are (3 3 2 3) with the optimum parameter as- 4000 700 1.25 12. The significant parameter are Feed>Diameter>DOC>Speed
iv) Gray Relational analysis method is successfully applied which gives the gray relational grade.
v) The optimum levels for combined objective function are 3 3 2 3 with the optimum parameter as - 4000 700 1.25 12 & the significant parameter are Feed>Speed>DOC>Diameter.

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