Optimization of Surface Grinding Process Parameters By Taguchi Method And Response Surface Methodology

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***Abstract*— In this study, the surface grinding process parameters were optimized by using Taguchi method and Response Surface Methodology (RSM). The process parameters considered in this study are grinding wheel abrasive grain size, depth of cut and feed. An AISI 1035 steel square rod of 100 mm x 10 mm x 10 mm was considered for grinding. The output response was selected as Surface roughness (R_a and R_z). In Taguchi method, L_{27} orthogonal array was selected and S/N ratios were analyzed to study the surface roughness characteristics. In response surface methodology, Box-Behnken method was used for optimization. Thirteen experiments were conducted in the surface grinding machine. The surface roughness values were entered in the Design Expert software and the optimal solution was obtained. Both methods showed that wheel grain size and depth of cut influences the surface roughness a lot. Feed of the surface grinding has a very minimal effect on the surface roughness value. This study showed that when the input parameters can be varied within the selected levels, Response surface methodology has an edge over Taguchi method. The confirmation experiments were conducted both for the optimal solution obtained from Taguchi and Response surface methodology.**

Keywords*— Optimization, Surface grinding, Surface roughness, Taguchi method, Response surface roughness, Optimal conditions

I. Introduction

Grinding is a finishing process, broadly used in manufacturing of components requiring fine tolerances, good surface finish and higher dimensional and geometrical accuracy. Compared with other material removal processes as an example of turning, milling and boring, the grinding process is more complex and more difficult to control. In addition to the static parameters of the grinding machine tool, there are many dynamic factors that contribute to resulting dimensional accuracy. Surface finish is very important for parts which will be in contact with other metal surfaces. The lower value of surface roughness causes less wear and friction. The lowest value of surface roughness gives the best surface finish [1].

The surface quality produced in surface grinding is influenced by various parameters such as [2], [3]: i. wheel parameters – abrasives, grain size, grade, structure, binder, shape and dimension; ii. workpiece parameters – fracture mode, mechanical properties and chemical composition; iii. process parameters – wheel speed, depth of cut, table speed and dressing condition; iv. machine parameters – static and dynamic characteristics, spindle system, and table system.

II. Literature Review

Yung-Tsan Jou [4] used Taguchi Method (TM) to screen the variables that have significant effects on the contraction rate of the outer coating of the optical fiber. The optimization engineering of Response Surface Methodology (RSM) is utilized for the empirical research to acquire a prediction model that can be used to optimize the optical fiber outer coating injection molding process. The research results show that the contraction rate predicted by the integration of the Taguchi Method and RSM is 2.28%.

Ilhan Asilturk [5] evolved a new method to determine multi-objective optimal cutting conditions and mathematic models for surface roughness (R_a and R_z) on a CNC turning. The cutting parameters namely, cutting speed, depth of cut, and feed rate were designed using the Taguchi method. The results indicated that the feed rate is the dominant factor affecting surface roughness, which was minimized when the feed rate and depth of cut were set to the lowest level, while the cutting speed is set to the highest level.

Jae Seob Kwak [6] studied that the geometric error in the surface grinding process was mainly affected by the thermal effects and the stiffness of the grinding system. He applied Taguchi and Response surface methodologies for controlling the geometric error. A second order response model for the geometric error was developed.

M.N. Dhavlikar [7] evoked a successful application of combined Taguchi and dual response methodology to determine robust condition for minimization of out of roundness error of workpieces for centerless grinding operation. From the confirmation runs, it was observed that this approach led to successful identification of optimum process parameter values.

In this journal, Grain size (M), Depth of cut (D) and the feed (f) were selected as the input parameters. Other process parameters were constant. Most of the surface grinding manufacturers produce surface grinding machine with constant spindle speed. Hence, the speed of the surface grinding is not included as the variable parameter. The average surface roughness (R_a) and average distance between the highest peak and lowest valley in each sampling length (R_z) were taken as the output parameter. Taguchi method and Response Surface Methodology (RSM) were used to optimize the parameters for minimum surface roughness. Minimum surface roughness indicates good surface finish. Confirmation experiments were conducted to verify the effectiveness of optimization.

III. EXPERIMENTATION

The experiments were carried out in Aarti horizontal spindle hydraulic surface grinding machine. AISI 1035 steel plates with the dimensions of 140 mm x 10 mm x 10 mm were used as the work material. The spindle speed is 2800 rpm. The experimental setup is shown in Fig 1.

The table size of the surface grinding machine is 500 x 200 mm. the maximum longitudinal travel the work bed can move is 550 mm while the maximum cross travel is 225 mm. the speed of the grinding wheel is constant at 2800 rpm. The size of the grinding wheel is 200 mm diameter, 20 mm thickness and 508 mm bore.

Three motors are present in the machine. The spindle motor which is used for the spindle rotation has a power of 2 HP. The hydraulic motor which causes the motion of the horizontal movement of the work bed has a capacity of 1 HP. The vertical motor for the vertical up and down movement of the spindle head has a capacity of 0.5 HP.

To reduce the thermal damage which will be produced during the interaction of work material and grinding wheel, coolant is used. It helps to reduce the heat as well as to wash away the grinded metal powder.

The output i.e. surface roughness was calculated using Mitutoyo Surftest SJ-400. The surface roughness (R_a and R_z) values were measured in µm. The sampling length was 4mm.

Figure 1. Experimental setup

TABLE I. GRINDING PARAMETERS AND THEIR LEVELS

Symbols	Controlled parameters	Level 1	Level 2	Level 3
M	Grain size (mesh)	36	46*	60
D	Depth of cut (mm)	0.05	0.10*	0.15
f	Feed (mm)	0.2	0.5*	0.8

* : initial parameters

A. Taguchi Method

The Taguchi Method uses parameter design to improve the quality by defining the target functions aiming at the quality required for improvement, identify the factors and levels in the target functions, and apply orthogonal arrays to determine the allocation of experimental factor. By computing the target function and transforming it into a Signal-to-Noise ratio, the Signal-to-Noise ratio of the quality characteristics is divided into the Larger the Better, Nominal the Better, and the Smaller the Better in the definition of Taguchi Method. This study aims to decrease the surface roughness of workpiece. The smaller the surface roughness, the better the grinding quality will be. In this case, the Smaller the Better (STB) is used to compute the Signal-to-Noise ratio of the surface roughness, as shown in equation (1).

$$SN_{STB} = -10 \cdot log_{10}(\frac{1}{n}\sum_{i=1}^{n} y_i^2) \tag{1}$$

where y_i is the performance response to the ith setting of the parameter combination, and n is the number of samples. L_{27} orthogonal array was used for the experimentation. The variability is inversely proportional to the S/N ratio, meaning that a larger S/N ratio corresponds to a more robust system. Following the analysis of variance (ANOVA), the experimental results are acquired by independently extracting the main effects of these factors and determining the statistically significant factors. This process identifies the controlling factors and optimizes the magnitude of the effects accordingly. The design of experiments is shown in Table II.

TABLE II. L_{27} ORTHOGONAL ARRAY

Exp. No.	Grain size	Depth of cut	Cross feed
	M (mesh)	V (mm)	f (mm)
1	36	0.05	0.2
2	36	0.05	0.5
3	36	0.05	0.8
4	36	0.10	0.2
5	36	0.10	0.5
6	36	0.10	0.8
7	36	0.15	0.2
8	36	0.15	0.5
9	36	0.15	0.8
10	46	0.05	0.2
11	46	0.05	0.5
12	46	0.05	0.8
13	46	0.10	0.2
14	46	0.10	0.5
15	46	0.10	0.8
16	46	0.15	0.2
17	46	0.15	0.5
18	46	0.15	0.8
19	60	0.05	0.2
20	60	0.05	0.5
21	60	0.05	0.8
22	60	0.10	0.2
23	60	0.10	0.5
24	60	0.10	0.8
25	60	0.15	0.2
26	60	0.15	0.5
27	60	0.15	0.8

B. Response Surface Methodology

In Response Surface Methodology, based on the responses acquired in the experiments, Regression Analysis is utilized to identify the relationships between the responses and the variables to establish a mathematical model that satisfies the relationship between a group of test factors and objective functions. This model is then used to explore the optimal solution in the experimental area.

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response.

Response surface modeling methods originally were developed to analyze experimental data and to create empirical models of the observed response values. The particular forte of RSM is its applicability to investigations where there are few observations because the physical experiment is both very expensive and very time consuming to perform.

Box and Behnken devised an experimental design for response surface methodology to find the optimal solution. Each design can be thought of as a combination of a two-level (full or fractional) factorial design with an incomplete block design. The total numbers of experiments were selected as thirteen. The sequences of experiments were given by the Design Expert software as shown in Table III. For three factors and three levels, there will be a total of 12 experiments. The number of centre blocks was selected as 1. The design layout is shown in Table III.

TABLE III. DESIGN LAYOUT

	Factor 1	Factor 2	Factor 3
Run	**M**	**D**	**f**
	mesh	mm	mm
1	60.00	0.10	0.20
2	46.00	0.05	0.20
3	60.00	0.05	0.50
4	36.00	0.15	0.50
5	46.00	0.10	0.50
6	60.00	0.10	0.80
7	36.00	0.05	0.50
8	60.00	0.15	0.50
9	36.00	0.10	0.80
10	46.00	0.15	0.80
11	46.00	0.05	0.80
12	46.00	0.15	0.20
13	46.00	0.15	0.20

IV. RESULT AND DISCUSSION

After conducting the experiments, the output responses (R_a and R_z) values were measured using Mitutoyo surftest SJ 4100 and the results were tabulated.

A. Optimization using Taguchi Method

Using Minitab 16 software, the S/N ratios were calculated and tabulated. The smaller the better phenomenon is chosen because surface quality will be high when the surface roughness values will be small.

1) Analysis of signal to noise (S/N) ratio: In this section, significance of controllable factors is investigated using S/N ratio approach. A smaller value of surface roughness is normally required in metal machining. Therefore, the smaller-the-better methodology of S/N ratio was employed for the aforesaid responses. Regardless of the category of the performance characteristics, the high value of S/N ratio corresponds to a better performance. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. The L_{27} orthogonal array with the corresponding S/N ratios for the R_a and R_z values are given in the Table IV.

Analysis of the influence of each control factor (M, D, f) on the surface roughness has been performed with a so- called signal-to-noise ratio response table. Response tables of S/N ratio for Ra and Rz are shown in Tables V and VI, respectively. They show the S/N ratio at each level of the control factors and how it is changed when settings of each control factor are changed from one level to another.

TABLE IV. L_{27} ORTHOGONAL ARRAY WITH S/N RATIOS

Exp. No.	**Grain size**	**Depth of cut**	**Cross feed**	**R_a**	**R_z**	**S/N ratio for R_a**	**S/N ratio for R_z**
	M (mesh)	**V (mm)**	**f (mm)**	**R_a (μm)**	**R_z (μm)**	dB	dB
1	36	0.05	0.2	0.09	0.7	20.9151	3.0980
2	36	0.05	0.5	0.11	0.9	19.1721	4.4369
3	36	0.05	0.8	0.11	0.6	19.1721	0.9151
4	36	0.10	0.2	0.13	1.0	17.7211	3.0980
5	36	0.10	0.5	0.12	0.7	18.4164	3.0980
6	36	0.10	0.8	0.13	0.7	17.7211	0.0000
7	36	0.15	0.2	0.18	1.0	14.8945	0.0000
8	36	0.15	0.5	0.18	1.1	14.8945	-0.827
9	36	0.15	0.8	0.20	1.3	13.9794	-2.278
10	46	0.05	0.2	0.08	0.5	21.9382	6.0206
11	46	0.05	0.5	0.09	0.5	20.9151	6.0206
12	46	0.05	0.8	0.09	0.5	20.9151	6.0206
13	46	0.10	0.2	0.11	0.8	19.1721	1.9382
14	46	0.10	0.5	0.10	0.6	20.0000	4.4369
15	46	0.10	0.8	0.11	0.8	19.1721	1.9382
16	46	0.15	0.2	0.14	0.8	17.0774	1.9382
17	46	0.15	0.5	0.18	0.9	14.8945	0.9151
18	46	0.15	0.8	0.17	1.3	15.3910	-2.278
19	60	0.05	0.2	0.07	0.5	23.0980	6.0206
20	60	0.05	0.5	0.07	0.5	23.0980	6.0206
21	60	0.05	0.8	0.08	0.6	21.9382	4.4369
22	60	0.10	0.2	0.10	0.8	20.0000	1.9382
23	60	0.10	0.5	0.10	0.7	20.0000	3.0980
24	60	0.10	0.8	0.11	0.7	19.1721	3.0980
25	60	0.15	0.2	0.12	0.7	18.4164	3.0980
26	60	0.15	0.5	0.13	0.8	17.7211	1.9382
27	60	0.15	0.8	0.13	0.9	17.7211	0.9151

TABLE V. RESPONSE TABLE FOR S/N RATIOS FOR R_A

Level	M (mesh)	D (mm)	f (mm)
1	17.43	21.24	19.25
2	18.83	19.04	18.79
3	20.13	16.11	18.35
Delta	2.70	5.13	0.89
Rank	2	1	3

TABLE VI. RESPONSE TABLE FOR S/N RATIOS FOR R_Z

Level	M (mesh)	D (mm)	f (mm)
1	1.28	4.77	3.01
2	2.99	2.52	3.23
3	3.39	0.38	1.48
Delta	2.11	4.40	1.82
Rank	2	1	3

2) Prediction of optimal solution: The influence of each control factor can be more clearly presented with response graphs (Fig 2 and 3). These figures reveal the level to be chosen for the ideal cutting parameters (the level with the highest point on the graphs), as well as the relative effect each parameter has on the S/N ratio (the general slope of the line). As seen in the S/N ratio effects graphs (Figs. 2 and 3), the slope of the line which connects between the levels can clearly shows the power of influence of each control factor. Especially the depth of cut and grain size has a strong effect on the surface roughness and its S/N ratios. The feed has a lower effect as evidenced by the shallow shape of the lines.

Table VII shows the results of analysis of variance (ANOVA) for R_a. The changes of the grain size and depth of cut in the ranges given in Table VII have significant effects on R_a. Therefore, based on the S/N and ANOVA analyses, the optimal cutting parameters for R_a is $M_3D_1f_1$ i.e., M_3 = 60 mesh, D_1 = 0.05 mm and f_1 = 0.2 mm.

Table VIII shows the results of ANOVA for R_z. In this case feed rate is the significant cutting factor for affecting R_z. The optimal cutting parameters for Ra is $M_3D_1f_2$ i.e., M_3 = 60 mesh, D_1 = 0.05 mm and f_2 = 0.5 mm.

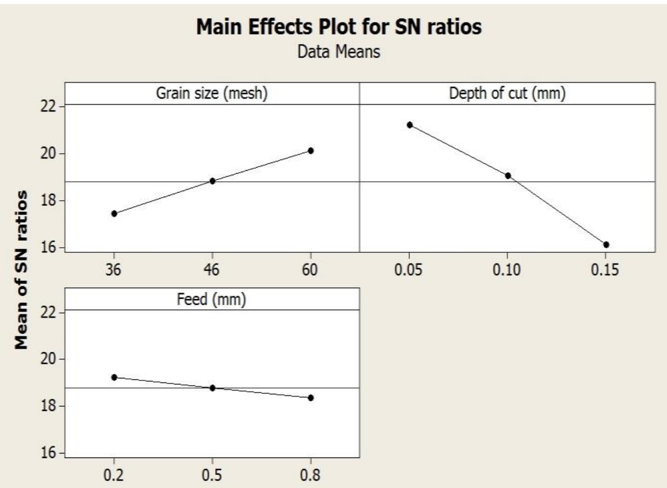

Figure 2. Main effect plot for S/N ratios for R_a

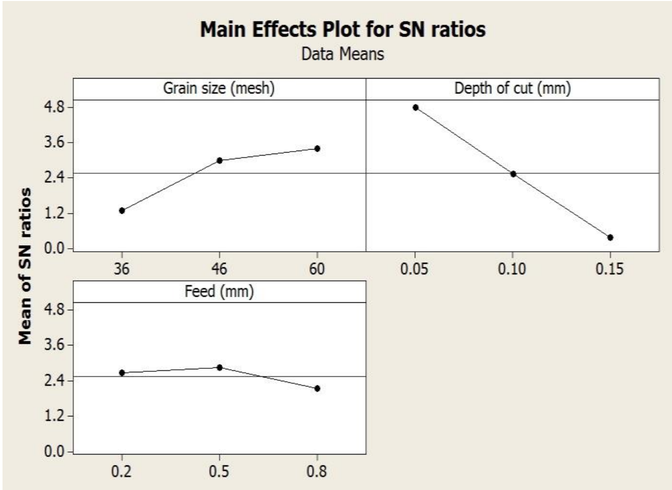

Figure 3. Main effect plot for S/N ratios for R_z

TABLE VII. ANOVA FOR R_A

Source	DOF	SS	MS	F	P	PC (%)
Grain size	2	0.00642	0.00321	25.76	0.000	19.43
Depth of cut	2	0.02349	0.01174	94.12	0.000	70.99
Feed	2	0.00067	0.00033	2.70	0.092	2.02
Error	20	0.00249	0.00012			
Total	26	0.03309				

TABLE VIII. ANOVA FOR R_Z

Source	DOF	SS	MS	F	P	PC (%)
Grain size	2	0.19185	0.09593	7.49	0.004	14.62
Depth of cut	2	0.68519	0.34259	26.73	0.000	52.23
Feed	2	0.17852	0.08926	6.97	0.005	13.61
Error	20	0.25630	0.01281			
Total	26	1.31185				

The Taguchi method revealed that the Depth of cut has a greater effect on the surface roughness values. The slope of the mean of S/N ratios for the depth of cut is very steep. This can been seen from the Fig. 2 and 3. The second major parameter is the grain size of the abrasive grinding wheel. While feed has a lower effect as evidenced by the shallow shape of the lines. For minimum surface roughness, the optimum solution of both Ra and Rz surface roughness values were obtained using the Taguchi method. The optimum level of the gridning factors are tabluated in the Table IX.

TABLE IX. FACTORS AND THEIR OPTIMUM LEVELS

Factors	Surface roughness	
	R_a	R_z
Grain size	Level 3 (60 mesh)	Level 3 (60 mesh)
Depth of cut	Level 1 (0.05 mm)	Level 1 (0.05 mm)
Feed	Level 1 (0.2 mm)	Level 2 (0.5 mm)

B. Optimization using Response Surface Methodology

The Design Expert software was used for the optimization using RSM. Box Behnken design was used. After conducting the experiments according to the design layout, the output responses i.e., Ra and Rz values were measured and entered into the design layout. The models were evaluated and ANOVA table for the quadratic response surface design were obtained.

1) Analysis of variance : The ANOVA table for both R_a and R_z surface roughness values were obtained. The adequacy of the response surface quadratic model was justified through ANOVA. The results are presented in Tables X and XI. It reveals that the first-order of grain size (M) and depth of cut (D) have significant effects on the R_a and R_z. On the contrary, the first-order of feed (f), quadratic and pairwise interactions of M, D and f have no significant effects on the roughness parameters.

In the Table X and XI, the Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case both the models are significant as the p-value "Prob > F" less than 0.0500. Values greater than 0.1000 indicate the model terms are not significant.

TABLE X. ANOVA FOR RA

Source	Sum of Squares	df	Mean square	F value	p-value Prob > F
Model	0.01200	9	0.00138	12.48	0.0308
A-Grain size	0.00245	1	0.00245	22.13	0.0182
B-Depth of cut	0.00887	1	0.00887	80.11	0.0029
C-Feed	0.00032	1	0.00032	2.92	0.1859
AB	0.00003	1	0.00003	0.26	0.6444
AC	0.00001	1	0.00001	0.13	0.7468
BC	0.00010	1	0.00010	0.90	0.4121
A^2	0.00037	1	0.00037	3.42	0.1617
B^2	0.00035	1	0.00035	3.23	0.1704
C^2	0.00012	1	0.00012	1.16	0.3602
Residual	0.00033	3	0.00011		
Cor Total	0.013	12			

TABLE XI. ANOVA FOR RZ

Source	Sum of Squares	df	Mean square	F value	p-value Prob > F
Model	0.71	9	0.0790	11.56	0.0343
A-Grain size	0.045	1	0.045	6.59	0.0827
B-Depth of cut	0.43	1	0.43	62.70	0.0042
C-Feed	0.049	1	0.049	7.17	0.0752
AB	0.012	1	0.012	1.83	0.2692
AC	0.045	1	0.045	6.52	0.0836
BC	0.063	1	0.063	9.16	0.0565
A^2	0.023	1	0.023	3.32	0.1659
B^2	0.0089	1	0.0089	1.31	0.3358
C^2	0.029	1	0.029	4.24	0.1317
Residual	0.020	3	0.0068		
Cor Total	0.73	12			

2) 3D Response surface plots : The quadratic response surface model the roughness parameters can be expressed as a function of the grinding parameters such as M, D and f.

$$R_a = +0.3800 - (0.0101 * M) - (0.2824 * D) - (0.1199 * f) - (0.0044 * M * D) + (0.00051 * M * f) + (0.3333 * D * f) + (0.00009 * M^2) + (5 * D^2) + (0.0833 * f^2) \quad (2)$$

$$R_z = +1.7700 - (0.0510 * M) - (0.0707 * D) - (0.4235 * f) - (0.0924 * M * D) + (0.0291 * M * f) + (8.3333 * D * f) + (0.0007 * M^2) + (25 * D^2) + (1.25 * f^2) \quad (3)$$

These model equations (2) and (3) can be used to predict the desired surface roughness values for the particular value of input parameters.

The 3D surface plots for the surface roughness parameters R_a and R_z are given in the Fig. 4 and 5 respectively. It is clear from Fig. 4 a and c that R_a decrease with decrease in depth of cut and feed rate. From Fig. 4b, it is observed that if grain size is increased, R_a is decreased. Therefore, the ideal combination of control factors for lowest surface roughness should consist of minimum depth of cut, minimum feed rate and maximum grain size in mesh.

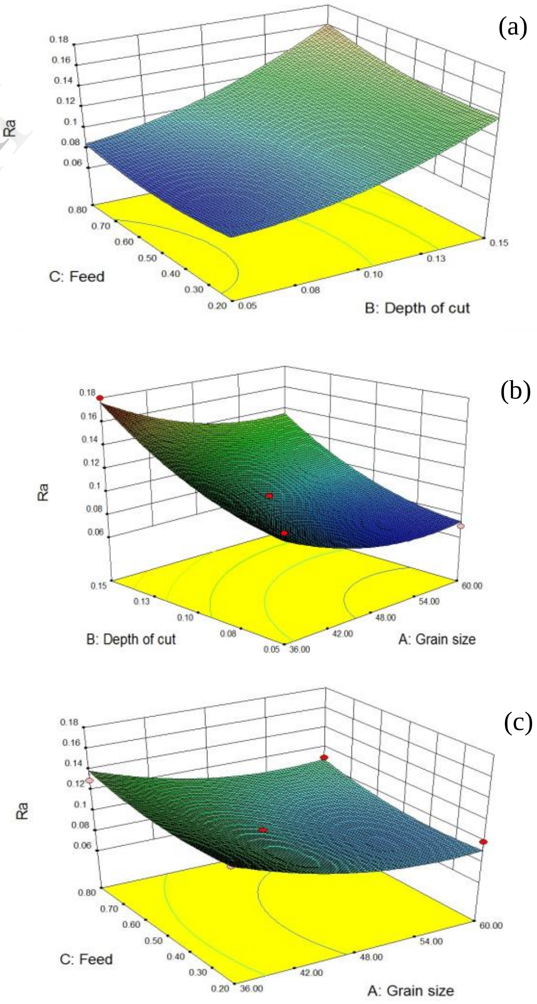

Figure 4. 3D Response for R_a
(the other variable is held at centre)

Fig 5 reveals that R_z increases with increase in depth of cut, feed rate. It decreases with the increase in grain size. Hence, a minimum level of depth of cut, a minimum amount of feed rate and maximum grain size is required for minimum R_z.

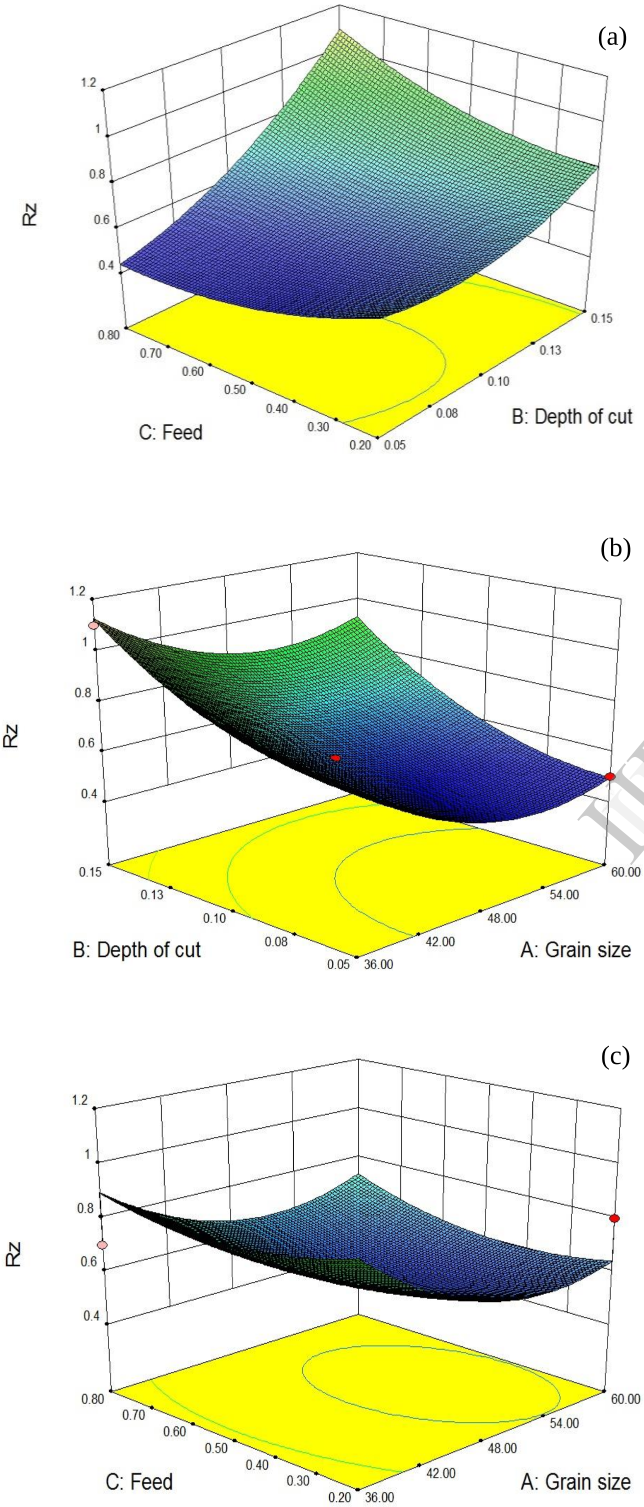

Figure 5. 3D Response for R_z
(the other variable is held at centre)

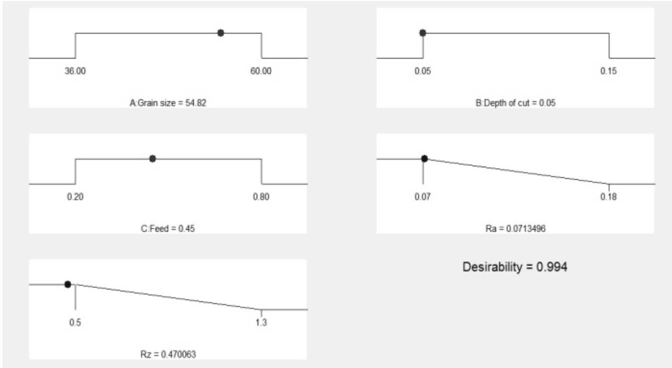

Figure 6. Optimum process parameters

3) Optimal solution : The goal was set to minimize the surface roughness values (R_a and R_z). Using the Design Expert software, fourteen otimal solutions were obtained. The solution with high desirabaility is chosen. The optimium process parameters chosen is shown in the Fig. 6.

The optimum process paramters obtained are grain size of 54.82 mesh, depth of cut of 0.05 mm and feed of 0.45 mm. grain size of 54.82 precisely is not available in the market. Therefore, grain size of 54 mesh can be taken as the otimum level for minimum surface roughness.

B. Confirmation experiments :

The confirmation experiments were conducted for both Taguchi and Response surface methods to validate the effectiveness of the optimum solutions obtained. The confirmation experiments validated the optimum solutions.

V. CONCLUSION

This study was done to find the optimum parameters for minimum surface roughness. Taguchi method and Response Surface Methodology were used for optimization. From the study, the following conclusions can be made:

- Statistically designed experiments based on Taguchi methods were performed using L_{27} orthogonal arrays to analyze the surface roughness as response variable. Conceptual S/N ratio and ANOVA approaches for data analysis drew similar conclusions.
- The minimum surface roughness (R_a) was obtained at grain size of 60 mesh, depth of cut of 0.05 mm, feed of 0.2 mm. For R_z, the optimum parameters were grain size of 60 mesh, depth of cut of 0.05 mm and feed of 0.5 mm obtained from Taguchi Method.
- Box Behnken designed experiments based on Response Surface methodology was done, with the surface roughness as the output response variable. ANOVA and 3D response plots were also analysed .
- The minimum surface roughness (Ra and Rz) were obtained at grain size of 54 mesh, depth of cut of 0.05 mm and feed of 0.45 mm by RSM.
- This study showed that when the input parameters can be varied within the selected levels, Response surface methodology has an edge over Taguchi method.

REFERNCES

[1] Mustafa Kurt, Uğur Köklü, Gürcan Atakök, Barkin Bakir, “An Experimental and Statistical Investigation on Shape Error in Interrupted Grinding”, Internatıonal Journal of Natural and Engineering Sciences , vol 1, pp.77-81, 2012.

[2] M.A. Kamely, S.M. Kamil, and C.W. Chong, “Mathematical Modeling of Surface Roughness in Surface Grinding Operation”, vol 5, pp.146-149, 2011.

[3] Mustafa Kemal Külekc, “Analysis Of Process Parameters For A Surface-Grinding Process Based On The Taguchi Method”, Materials and technology, vol 4, pp.105–109 , 2013.

[4] Yung-Tsan Jou, Wen-Tsann Lin, Wei-Cheng Lee1 and Tsu-Ming Yeh, “Integrating the Taguchi Method and Response Surface Methodology for Process Parameter Optimization of the Injection Molding”, Internatıonal Journal of Applied Mathematics & Information Sciences , vol 8, No. 3, pp. 1277-1285, 2014.

[5] Ilhan Asiltürk, Süleyman Neseli, “Multi response optimisation of CNC turning parameters via Taguchi method-based response surface analysis”, Measurement, vol 45, pp.785-794, 2012.

[6] Jae-Seob Kwak, “Application of Taguchi and response surface methodologies for geometric error in surface grinding process”, International Journal of Machine Tools & Manufacture 45 (2005) 327–334, vol 45, pp.327–334 , 2005.

[7] M.N. Dhavlikara, M.S. Kulkarnib, V. Mariappanc, “Combined Taguchi and dual response method for optimization of a centerless grinding operation”, Journal of Materials Processing Technology, vol 321, pp.90-94, 2003.

[8] Kalpakjian Schmid, 2008,”Manufacturing Processes for Engineering Materials”, Pearson Education, 5th ed., ISBN No. 0-13-22727.

[9] S.K.Hajra Choudhury, A.K. Hajra Choudhury 2008, “Elements of Workshop Technology”, Media Promoters & Publishers, Volume II Machine Tools, 12th ed., ISBN No. 81.85099-15-4.