Prediction and Optimization of Process Parameters for Cylindrical Grinding of Inconel718 Alloy using Taguchi Approach

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***Abstract*— This paper discusses the use of Taguchi for minimizing the surface roughness in machining Nickel based alloy (Inconel 718) with a Silicon carbide grinding wheel. The experiments have been conducted using Taguchi's experimental design technique. The cutting parameters such as grit size, depth of cut and coolants are used. The effect of cutting parameters on surface roughness is evaluated and the optimum cutting condition for minimizing the surface roughness is determined. The experimental results reveal that the most significant machining parameter for surface roughness is depth of cut followed by grit size. The predicted values and measured values are fairly close, which indicates that the developed model can be effectively used to predict the surface roughness in the machining of Nickel based alloy. The validation experiments have also been done to confirm the predicted value.**

Keywords—cylindrical grinding; taguchi design; ANNOVA; MRR

I. INTRODUCTION

The quality of surface finish is a significant factor in assessing the productivity of machined parts in machining operations. Surface finish quality of the components can be enhanced by grinding processes. In particularly, cylindrical grinding is an intricate, material removal process with an immense number of influencing parameters, which are nonlinear, interdependent and complex to compute. To maximize the surface quality, the selection of grinding parameters is essential. Numerous factors influence the grinding process that a reproducible workpiece quality is hardly ever, if ever, achieved. Although a lot of efforts have been made to envisage the parameters of the grinding process, many difficulties continue since the cutting edges of the grinding wheel are not identical and perform in a different way on the workpiece at each grinding processes are dynamic in nature.

The prediction of the parameters of grinding process is essential to quantify surface roughness, which is one of the significant quality limitations for the selection of grinding parameters in process planning. Usually, practical knowledge gained by the process planners and help of data handbooks is used to select the grinding parameters [1, 2]. On the other hand, the process may be time consuming and cannot convince any financial criteria; also it cannot establish the precise optimal parameters because of limited experiments [3]. Additionally, these results are not consistent or satisfactory for deciding the optimal cutting parameters from a productivity attitude. Efficient process set-up should be model based in which the necessary surface roughness is obtained.

Statistical design of experiments (DOE) refers to the process of planning the experiment so that the suitable data can be examined using statistical techniques, ensuing in valid and objective conclusions [4-7]. DOE methods such as factorial design, RSM and Taguchi method are now extensively used for optimize the machining parameters instead of one factor at a time experimental approach which is prolonged and very expensive [8]. To this end, a lot research has been carried out to decide optimum process parameters and to apply various optimization methods to grinding variables of wheel speed, workpiece speed, depth of dressing, and lead of dressing using a multi-objective function model weighted approach [9-13].

Lee at al. [14] anticipated to solve the problem of optimization for the surface grinding process by using optimizing the grinding variables such as wheel speed, workpiece speed, depth of dressing, and lead of dressing, using a multi-objective function model. This research provided rough grinding and finish grinding results that demonstrated the applicability of the proposed Taguchi sliding based differential evolution algorithm, and the computational results showed that this proposed Taguchi sliding(based differential evolution algorithm can obtain better results.

Krishna and Rao [15] proposed a scatter search based optimization approach to optimize the grinding parameters of wheel speed, workpiece speed, and depth of dressing and lead of dressing using a multiobjective function model with a weighted approach for the surface grinding process.

Habib [16] developed a comprehensive mathematical model for correlatingthe interactive and higher order influences of various Electrical discharge machining EDM) parameters through RSM, utilizing relevant experimental data as obtained through experimentation.

An additional main work was offered by Agarval and Rao[17] about grinding parameter optimization. As a result of their study, a innovative analytical surface roughness model was developed on the basis of the stochastic nature of the grinding process, governed mainly by the random geometry and the random distribution of cutting edges on the wheel surface having random grain protrusion heights.

Malkin [18] investigated the process monitoring and studied various grinding aspects such as cutting mechanisms, the specific energy and the interrelationship of the parameters. His research showed that the grinding process had very complex cutting mechanisms and that replicability of results was difficult to obtain under the same grinding conditions.

Shaji [19] reported a study on the Taguchi method for evaluating process parameters in surface grinding with graphite as a lubricant. They analyze the effect of the grinding parameters (wheel speed, table speed, depth of cut and the dressing mode) on the surface finish and the grinding force.

Kwak [3] showed that the various grinding parameters caused a geometric error generated during the surface grinding, using the Taguchi method, and that the geometric error could be predicted by means of the response surface method. Usually, the equation for predicting cutting time is unknown during the early stages of cutting operations.

Jeang [20] studied to determine the optimal cutting parameters required to minimize the cutting time while maintaining an acceptable quality level. He formulated an objective function using CATIA software, with assistance from the statistical method and response surface methodology (RSM). Results showed the statistical method in cooperation with the optimal solutions found from mathematical programming can also be used as references for the possibility of robust design improvements.

This paper demonstrates how response surface designs and orthogonal array fractions can be used in a sequence of grinding experiments to devise high performance robust manufactured goods. Taking this study a step advance, the Taguchi and ANNOVA are used to envisage the surface roughness in the external cylindrical grinding of the Inconel718 alloy and also to decide the optimal grinding environment. Also, this research would benefit from future applications, particularly as initiated in real-time application such as production shop floors. It is also advantageous to carry out studies related to this in academic world as class learning exercise.

II. Design of Experiments

A. *Taguchi* design

Taguchi design methods are robust statistical methods devised by Genichi Taguchi to optimize the process constraints and to improve the quality of products. Contrast to conventional experimental designs that focus on the average characteristics obtained by some experiments, the Taguchi method uses a unique design of orthogonal array to inspect the quality characteristics through a least number of experiments. The experimental results based on the orthogonal array are then transformed into signal to noise (S/N) ratios (dB) to evaluate the quality characteristics [31].

TABLE I. $L_{27}(3^{13})$ ORTHOGONAL ARRAY

Trial No	Control Factors		
	X	Y	Z
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3
19	3	1	1
20	3	1	2
21	3	1	3
22	3	2	1
23	3	2	2
24	3	2	3
25	3	3	1
26	3	3	2
27	3	3	3

In this study, the Taguchi method is utilized to establish the optimal external cylindrical grinding process parameters. The configuration of orthogonal array is based on the total degree-of- freedom (TDOF) of the objective function. The most suitable array is L27 (3^{13}), which needs 27 runs and as 26 TDOF. To check the TDOF in the experimental design for the three levels of the test the three main factors take 6 TDOF (3×2) and the remaining TDOF are taken by interactions. The experimental plan is given in Table 1 using L27(3^{13}) Taguchi regular orthogonal array.

III. Experimental Procedure

A. *Selection of factors and their level*

A sequence of experiments has been conducted to assess which grinding factors affect workpiece surface roughness. The grinding factors and their levels for the experiment are identified using previous studies carried out various researchers. Finally, three parameters were decided that can be associated with workpiece surface roughness. The factors and levels identified are given in Table 2. The other factors such as workpiece material, wheel speed, work speed and feed rate were constant.

B. *Materials and methods*

In this present investigation, the Inconel 718 alloy is used. The Inconel 718 alloy is purchased from Keshariya Metal Pvt Ltd., Mumbai. The mechanical properties and chemical composition of the Inconel 718 alloy is illustrated in the table 3 and table 4 respectively. A 30mm diameter cylindrical specimen is used in this study. A conventional grinding machine is used to conduct the experiments. The cutting experiments were carried out on the cylindrical grinding machine. The Cutting tests were conducted using silicon-carbide grinding wheel of various girt sizes abrasives with vitrified bond. The grinding parameters include: grit size, depth of cut and coolants.

After the experiments, the surface roughness value measured by Mitutoyo Surftest SJ-201 stylus type surface texture measuring instrument, and the mean roughness values measured from three different points of the machined surface were calculated. In this paper a robust approach has been represented which uses both the Taguchi and Anova to obtain optimum combination for the grinding parameters. For this purpose, the first step in the optimization process is to determine the S/N ratio for all the experimental runs by using the Taguchi methodology. The next step is to find the objective function. The objective function is formulated using the Taguchi methodology.

TABLE II. CONTROL FACTORS AND THEIR LEVELS FOR GRINDING

Symbol	Control factor	Unit	Level 1	Level 2	Level 3
A	Grit size	-	GC60	GC120	GC180
B	Depth of cut	mm	0.01	0.02	0.03
C	Coolants	-	A	B	C

where A-Cutting oil, B-Sunflower oil, C-Coconut oil.

TABLE III. MECHANICAL PROPERTIES OF INCONEL 718

Properties	Units	Values
Ultimate Tensile Strength	MPa	1240
Yield Strength	MPa	1036
Elongation	%	12
Elastic Modulus	GPa	211
Hardness	HRC	43

TABLE IV. CHEMICAL COMPOSITION OF INCONEL718 (% WEIGHT)

Ni	Cr	Cu	Mo	Nb	C	Co
50-55	17-21	0.3	2.8-3.3	4.75-5.5	0.08	1.0
Mn	**P**	**S**	**Si**	**Ti**	**Al**	**B**
0.35	0.015	0.015	0.35	0.65-1.15	0.2-0.8	0.006

IV. RESULTS AND DISCUSSIONS

A. *Analysis of the signal-to-noise ratio*

There are several types of quality characteristics, such as the lower-the-better, the higher-the-better and the nominal the better in the case of vibration and surface roughness that should be a minimum. In this study, therefore, the smaller the better type of the signal to noise (S/N) ratio has been used and is defined as follows:

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \tag{1}$$

where n is the number of repeated experiments for each combination of control factors, and y_i is the observed response at ith trial. The negative sign in Eq. (1) is for showing the smaller the better quality characteristic. The response y in this case is the surface roughness, respectively. Response tables of S/N ratio for surface roughness are given in Table 5 along with their experimentally measured values.

The S/N ratio for each level of factors is calculated based on the S/N analysis using Eq. (1). A smaller value of surface roughness is usually necessary in metal machining. Therefore, the smaller the better methodology of S/N ratio was employed for the aforesaid responses. Response tables of S/N ratio for surface roughness are shown in Tables 5 and 6, respectively. They show the S/N ratio at each level.

TABLE V. EXPERIMENTAL RESULTS FOR RESPONSES AND THEIR S/N RATIOS

Trial No	Control Factors X Grit size	Y Depth of cut	Z Coolants	Surface roughness Ra (µm)	S/N Ratio Ra (µm)
1	60	0.01	A	0.154	-8.45
2	60	0.01	B	0.173	-7.68
3	60	0.01	C	0.151	-7.14
4	60	0.02	A	0.145	-20.11
5	60	0.02	B	0.202	-18.35
6	60	0.02	C	0.164	-17.30
7	60	0.03	A	0.235	-25.31
8	60	0.03	B	0.155	-24.61
9	60	0.03	C	0.287	-23.62
10	120	0.01	A	0.233	-8.03
11	120	0.01	B	0.174	-6.08
12	120	0.01	C	0.194	-6.49
13	120	0.02	A	0.214	-18.99
14	120	0.02	B	0.137	-17.40
15	120	0.02	C	0.142	-16.44
16	120	0.03	A	0.151	-24.27
17	120	0.03	B	0.157	-23.81
18	120	0.03	C	0.150	-22.13
19	180	0.01	A	0.136	-6.60
20	180	0.01	B	0.157	-5.99
21	180	0.01	C	0.114	-5.29
22	180	0.02	A	0.153	-17.18
23	180	0.02	B	0.175	-16.63
24	180	0.02	C	0.149	-15.41
25	180	0.03	A	0.179	-22.50
26	180	0.03	B	0.165	-22.81
27	180	0.03	C	0.232	-21.61

The control factors and how it is changed when settings of each control factor are changed from one level to another. The influence of each control factor can be more clearly presented with response graphs (see Fig.1). These figure 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. 3 and 4), the slope of the line which connects between the levels can clearly show the power of influence of each control factor. Especially, the grit size and depth of cut are shown to have a strong effect on surface roughness and their S/N ratios. The coolant had a smaller effect, as evidenced by the shallow slope of the lines. An analysis of variance (ANOVA) summary table is most widely used to summarize the test of the regression model, test of the significance factors on response and their lack of fit test

B. *ANOVA*

The ANOVA procedure performs Analysis of variance for balanced data from a wide variety of experimental designs. In analysis of variance, a continuous response variable, known as dependent variable, is measured under experimental conditions identified by classification variables, known as independent variables . The variation in the response is tacit to be due to effects in the classification, with random error accounting for the remaining variation.

TABLE VI. RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS SMALLER IS BETTER

Level	Grit size	Depth of cut	Coolants
1	-16.953	-6.861	-16.825
2	-15.959	-17.535	-15.929
3	-14.891	-23.407	-15.049
Delta	2.061	16.547	1.777
Rank	2	1	3

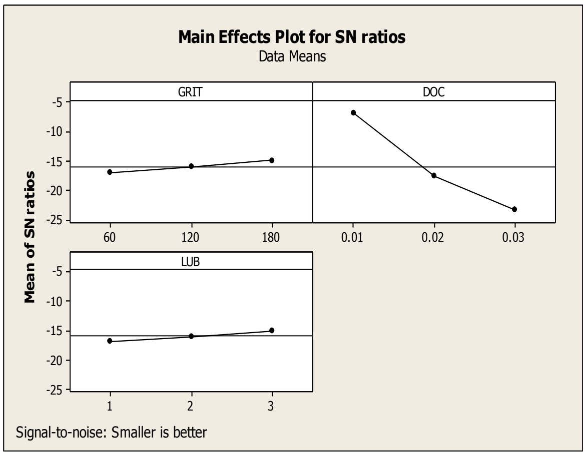

Fig. 1. Effect of process parameters on Ra

V. CONCLUSIONS

In this study an experimental investigation performed to evaluate the surface roughness of Inconel 718 in cylindrical grinding operation has been presented. The obtained data have been statistically processed using ANNOVA. The empirical models of output parameters are established and tested through the analysis of variance to validate the adequacy of the models. A Taguchi optimization is attempted using Minitab software for output responses in cylindrical grinding process.

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