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Optimization of Grinding Parameters for Minimum Surface Roughness using Taguchi Method

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ABSTRACT
The main aim of the machining is to obtain minimum surface roughness and smooth surface contains less wear and friction coefficients. Good surface quality has proper quality of functioning of the parts of product which is influenced by hardness, cutting speed, depth of cut, feed rate etc. In this experiment, FSG-1224 AD (1500 rpm) surface grinding machine is used for surface finishing, hardness is measured by Rockwell Hardness Tester (HRC) and TR-200 is used for measuring surface roughness. Mathematical model is developed to predict surface roughness using the experimental results with the help of Minitab 1513 software. Analysis of variance (ANOVA) was carried out to identify the significant factors affecting the response and the best possible factor level combination was determined through. Finally, a regression model for minimum surface roughness has been developed. The conducted optimal condition which is comparing with experimental results and predicted values.

Keywords: Surface Grinding Machine, Taguchi Method**,** Surface roughness, *S/N* ratio, Regression modeling.

1. Introduction

Production engineering is under constant pressure to satisfy industrial demands for improved productivity while simultaneously achieving high work piece quality. Furthermore, growing environmental awareness is an additional requirement that production engineers must increasingly address. There are still several gaps in the evaluation of process eco-efficiency and material effectiveness [1]. A typical surface is characterized by clean cutting paths and plowed material to the sideway of some grooves. However, many other marks can be found, such as cracks produced by the thermal impact, back-transferred material and craters produced by a grain fracture. Thus, need to machine to achieve smooth surfaces and high dimensional accuracy. Surface Grinding is an abrasive machining process widely used for the final shaping of components that require very smooth surfaces and a high dimensional accuracy. The performance attainable in this process as measured by levels of productivity, cost, and final part quality is determined by the selected combination of (i) the machine tool, (ii) work piece material (iii) grinding wheel (iv) setup parameters, (v) grinding parameters and (vi) grinding fluid [2]. In many cases, the selected parameters are too conservative and not adapted to maximize the utility of the machine tool and the grinding wheel. A similar practice is prevalent in the selection of grinding fluid application settings, where different oils are typically used to flood the grinding contact zone without considering more effective alternatives [3]. Although grinding has been used extensively in the production of precision components, these common practices confirm that it still remains one of the least understood and most inefficiently conducted machining process in the manufacturing industry.

2. Objectives

I. The main objective in this machining process is to minimize the surface roughness (Ra).
II. To determine the significant grinding parameters on the key process performance responses. (Feed force, Feed, Depth of cut, Temperature, System Roughness)
III. To optimize the grinding parameters.

3. Literature review

Nowadays, grinding is a major manufacturing process which accounts for about 20-25% of the total expenditure on machining operations in industrialized countries. In the grinding process, material is removed from the work piece by a rotating abrasive wheel. The grinding process can be classified into three parts; which are surface, cylinder and center less grinding. These processes are choose regarding with work piece shape. Surface grinding is the common operation for grinding flat surface and is likely to produce high tolerances, low surface roughness and planar surfaces. In surface grinding, shallow depth of cut is achieved with fast feed rates and the depth of cut can range from 0.01 to 0.05mm while feed rate is approximately 3m/s [4].The cutting speed, feed rate, and depth of cut have the greatest influence on the surface roughness. Increasing the feed rate significantly increases the surface roughness, as well as the depth of cut using the Taguchi method. Akkus et al. Found that the feed rate is the most significant factor that contributes to the surface roughness using ANOVA and regression. Chowdhury et al. Noticed that the rate of growth of flank wear increases irrespective of feed, with an increase in speed under both minimum quantity lubrication and dry conditions. According to

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Grzesik&Wanat the results show that by keeping equivalent feed rates (0.1 mm/rev for conventional, and 0.2 mm/rev for wiper inserts), the obtained surfaces have similar roughness parameters and comparable values of skewness and kurtosis. With wiper inserts and a high feed rate it is possible to obtain machined surfaces with <0.8 μm of Ra compared with conventional inserts that present high values of surface roughness. Kushnaw et al. Observed that the main factor affecting the inclination angle is the diameter of the periphery, and machined diameters depend on change in depth of cut and the cutting condition. Choudhury et al. discussed the development of surface roughness prediction models for turning EN 24T steel (290 BHN) using a response surface methodology. A factorial design technique was used to study the effects of the main cutting parameters such as cutting speed, feed, and depth of cut on surface roughness. The tests were carried out using uncoated carbide inserts without any cutting fluid [5].

4. Methodology

4.1 Taguchi Method

Taguchi method is the process of engineering optimization in a three steps approach namely system design, parameter design and tolerance design. In the system design, a basic functional prototype design will be produced by applying scientific and engineering knowledge. In parameter design, independent process parameter values will be optimized and where as in tolerance design, tolerances will be determined and analyzed for optimal values set by parameter design. Taguchi method is a powerful design of experiments (DOE) tool for optimization of engineering processes [6]. Steps of taguchi method is given in Fig.1.

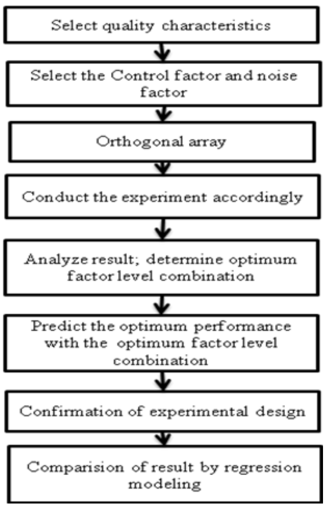

Fig.1 Steps of taguchi method

4.2 Experimental Procedur**e**

In the present work, mild steel, cast iron and carbon steel have been selected for work materials. The work materials are 6 inch in length, 3 inch in width and 3/4 inch height. After filling, work pieces are grinded in surface grinding machine. (FSG-1224 AD, 1500 RPM), grinding spindle drive speed 50Hz/150, power rating 3.7 KW. Aluminum grinding wheel- WA36G5VBE is used as grinding wheel. Dioxol.M used as cutting fluid. The various process parameters of a surface grinding machine include depth of cut, material hardness, and work piece speed, grinding wheel grain size, and grinding wheel speed. The input processes parameters namely material hardness, work piece speed and depth of cut. The other parameters such as abrasive type and feed rate are kept constant. The number of experiments to be conducted can be reduced by using orthogonal array method of Taguchi optimization technique. Experimental Set-up for surface grinding is given in **Fig.2**.

Fig.2 Experimental Set-up for surface grinding

Selected process parameters are given in **Table 1**.

Table 1 Selected process parameters

Level	Hardness(HRC)	Work piece speed (ft/min)	Depth of cut(mm)
1	15	38	0.001
2	25	44	0.005
3	36	48	0.01

Surface roughness values are obtained from Surface Roughness Tester TR-200 Surface roughness tester for each experiment. The obtained values used for the Taguchi optimization process. L9 orthogonal array surface with roughness values is given in **Table 2**.

Table 2 L9 orthogonal array surface with roughness values

Exp.No.	Hardness	Work piece speed	Depth of cut	Ra
1	15	38	0.001	0.763
2	15	44	0.005	0.630
3	15	48	0.01	0.382
4	25	38	0.005	0.470
5	25	44	0.01	0.396
6	25	48	0.001	0.470
7	36	38	0.01	0.291
8	36	44	0.001	0.429
9	36	48	0.005	0.300

In the Taguchi method, the term ‘signal’ and ‘noise’ denote respectively ‘desirable’ and ‘undesirable’ value. Signal to Noise ratio is found out in each case using the criteria ‘lower is better’ as surface roughness is the factor of consideration. The objective of using the S/N ratio as a performance measurement is to develop products and processes that are insensitive to the noise factor.

Lower is better S/N = -10 log [1/n (Σyi2)] (n=1)

From this equation where n represents the number of experimental run. Signal to noise ratio for various experiments is given in **Table 3**.

Table 3 Signal to noise ratio for various experiments

Exp. No.	SNRA1
1	2.3495
2	4.0132
3	8.3587
4	6.5580
5	8.0461
6	6.5580
7	10.7221
8	7.3509
9	10.4576

Average S/N ratio for each parameter at each level is found out. Similarly the average surface roughness values for each parameter at each level are also found out. Average S/N ratios in each level, a main effect for S/N ratio, average surface roughness values in each level and effect of process parameter on roughness are given in **Table 4**, **Fig.3**, **Table 5** and **Fig. 4** respectively.
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Table 4 Average S/N ratios in each level

Level	Hardness	Work piece speed	Depth of cut
1	4.907	6.543	5.413
2	7.048	6.470	7.010
3	9.510	8.452	9.042
Delta	4.603	1.982	3.629
Rank	1	3	2

From the table 5, hardness greatly influenced the surface roughness (Ra), followed by the depth of cut and work piece speed. Based on table 5,the optimum conditions for this study are 36(HRC),48(ft/min) and 0.01(mm) for hardness, work piece speed and depth of cut. So signal to noise ratio is high in level 3.The difference between the largest and minimum signal to ratio is calculated and the factors effect are ranked based on it.

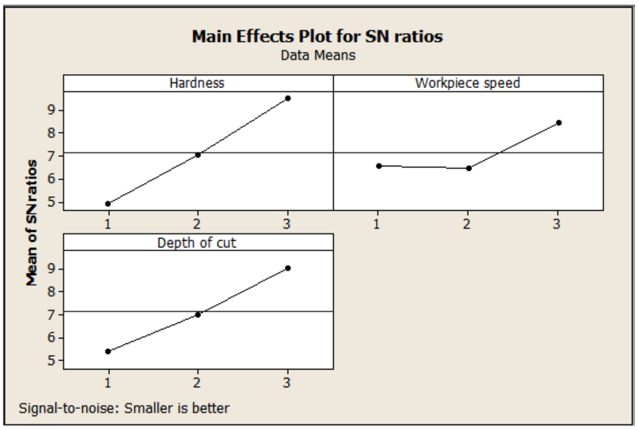

Fig.3 Main effects for S/N ratio

I. Level III for Hardness, H_3 = 9.510dB indicated as the optimum situation in terms of S/N values.
II. Level III for Cutting Speed, W_3 = 8.452dB indicated as the optimum situation in terms of S/N values.
III. Level III for depth of cut, D_3 = 9.042dB indicated as the optimum situation in terms of *S/N* values.

Table 5 Average surface roughness values in each level

Level	Hardness	Work piece speed	Depth of cut
1	0.5917	0.5080	0.5543
2	0.4457	0.4850	0.4667
3	0.3400	0.3843	0.3563
Delta	0.2517	0.1237	0.1980
Rank	1	3	2

From the table 6, at level 3(hardness, work piece speed and depth of cut), the surface roughness (Ra) is low. The difference between the largest and minimum signal to ratio is calculated and the factors effect are ranked based on it. As this table hardness greatly influenced the Ra, followed by the depth of cut and work piece speed. The optimum conditions for this study are 36(HRC), 48(ft/min) and 0.01(mm) for hardness, work piece speed and depth of cut.

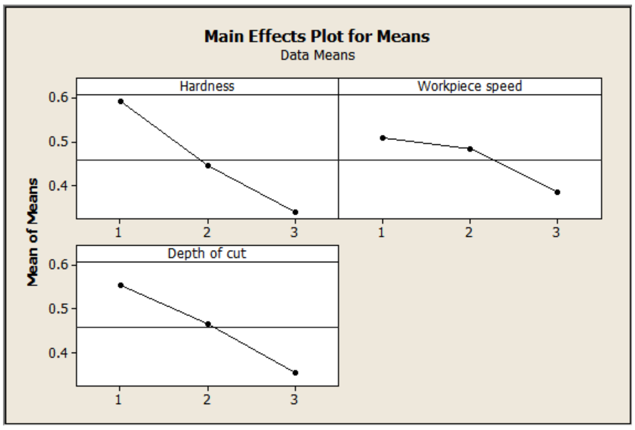

Fig. 4 Effect of process parameter on roughness

I. Level III for Hardness, H_3 = 0.3400Ra indicated as the optimum situation in terms of Surface Roughness values.
II. Level III for Cutting Speed, W_3 = 0.3843Ra indicated as the optimum situation in terms of Surface Roughness values.
III. Level III for depth of cut, D_3 = 0.3563Ra indicated as the optimum situation in terms of Surface Roughness values.

4.3 Interaction Plot

Whether interactions between factors exist or not can be shown by plotting a matrix of interaction plot. Parallel lines in an interaction plot indicate no interaction. However, the interaction plot doesn't tell if the interaction is statistically significant. Interaction plots are most often used to visualize interactions during DOE. Interaction Plots are used to compare the relative strength of the effects across factors [7]. Interaction plot for SNRA1of Ra is given in **Fig.5**.

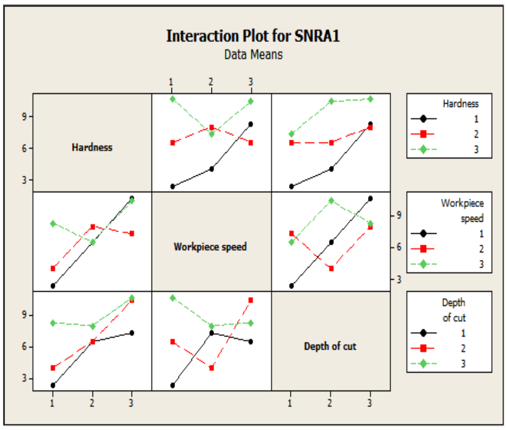

Fig.5 Interaction plot for SNRA1of Ra

From these figure (5 and 6), it can be seen that there are non-parallel line between hardness, workpiece speed and depth of cut. So, all factors depend on each others.

5. Calculations and result

5.1 ANOVA test

One way ANOVA test is used for obtaining the F value. Analysis of variance (ANOVA) of Ra is given in **Table 6**.

Table 6 Analysis of variance (ANOVA) of Ra

Source	DF	SS	MS	F	P
Regression	1	58.143	58.143	281.42	0.000
Residual error	2	1.446	0.207		
Total	8	59.589			

From this table F-value is 281.42 and P vale zero. that means there is a significant relationship between the response variable. To generalize the results, the Modeling of input parameters (Hardness, work piece speed, grains) and output parameter (Roughness) is done using Regression Modeling and Minitab1513 Software. Regression equation, different residual plots for testing the adequacy of the proposed model and Run test: Experiment No. *Ra* are given in **Table 7, Fig.6** and **Table 8** respectively.

Table 7 Regression equation

The regression equation is SNRA1=15.3-17.7 surface roughness

Predictor	Coef.	SE Coef.	*T*	*P*
Constant	15.2680	0.5067	30.130	0.000
Ra	-17.671	1.053	-16.78	0.000

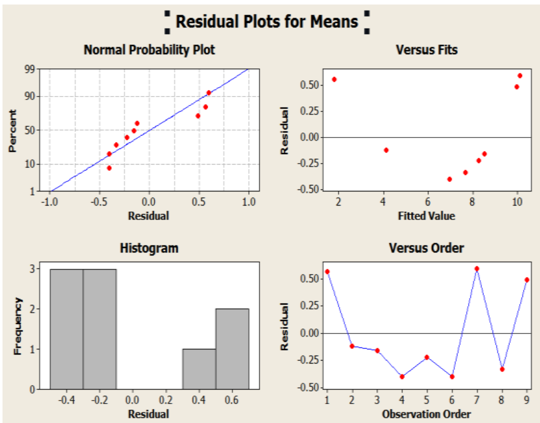

Fig.6 Different residual plots for testing the adequacy of the proposed model

I. Normal probability plot indicates the data are normally distributed and the variables are influencing the response. Outliers don't exist in the data
II. Residuals versus fitted values indicate the variance is constant and a non-linear relationship exists.

III. Histogram proves the data are not skewed and no outliers exist.
IV. Residuals versus order of the data indicate that there are systematic effects in the data due to time or data collection order.

Table 8 Run test: Experiment No. *Ra*

Runs test for experiment no. Runs above and below K=5
The observed no. of runs=2 The expected no. of runs=5.4444 4 observations above K,5 below *N is small, so the following approximation may be invalid. P-value=0.013
Runs test for surface roughness Runs above and below K=0.459
The observed no. of runs=6 The expected no. of runs=5.4444 4 observations above K,5 below *N is small, so the following approximation may be invalid. P-value=0.688

Confirmation experiments were conducted at the optimum set of the process parameters. The value of surface roughness at the optimum set of the process parameters was 0.340 µm and it fall near the predicted value of 0.300 µm. The difference between the value of the minimum and the actual surface roughness (*Ra*) is about 36%. Conformation of experiment is given in **Table 9**.

Table 9 Conformation of experiment

Surface roughness(Ra)	S/N ratio (dB)
0.300	10.4576

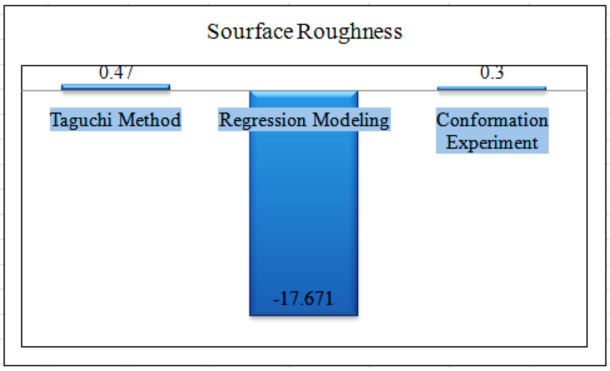

Fig.7 Comparisons of results

6. Conclusions

From main effects plotted, it is observed that there is decrease in surface roughness as material hardness increased from -15 to 36. The surface roughness decreases when work piece speed increases from 38 to 48 ft/min, similarly when depth of cut increases from 0.001 to 0.01mm surface roughness decreases. It can be observed that the difference between the value of the minimum and the actual surface roughness (*Ra*) is about 36%.

NOMENCLATURE

R_a : surface roughness
rpm : revolution per minute
HRC : Rockwell Hardness C scale
mm : millimeter
ft/min : feet per minute
ANOVA: Analysis of variance
µm : micrometer
DOE : Design of experiment
Kw : kilowatt
S/N : Signal to Noise Ratio
db : decibel
DF : Degree of freedom
SS : Sum of square
MS : Mean of square
F : statistical parameter
P : percentage

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