Analysis and Optimization of Surface Roughness in Grinding Operation of High Carbon High Chromium Steel by Taguchi

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***Abstract* — *Grinding is a material removal process by the application of abrasives. Abrasives are bounded to form a grinding wheel. When the moving abrasive particles come in contact to the work piece they act as cutting tools. Grinding wheel is considered as multi-point cutting tool. These cutting tools remove the material in form of micro chips. Metal removal rate and surface finish are the important output responses in the production with respect to quantity and quality respectively. In this experiment Taguchi method that is a powerful tool to design optimization for quality is used to find the optimum surface roughness in grinding operation. An orthogonal array, a signal-to-noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate the surface roughness characteristic for grinding operations. The effects of Grain size, Depth of Cut, cross feed, have been evaluated on the surface roughness of work piece. The effect of all input parameters was analyzed on output response. Plots of significant factor and S/N ratio have been used to optimize the control parameters to minimize the surface roughness.*

Keywords — *HCHC steel, DOE, Taguchi, Optimization, ANOVA, Surface Roughness.*

I. INTRODUCTION

Among various cutting processes, grinding process is one of the most fundamental and most applied metal removal operations in a real manufacturing environment. The surface roughness of the machined parts is one of the most significant product quality characteristic which refers to the deviation from the nominal surface. Surface Roughness (finish) is one of the key performance parameters that have to be controlled within suitable limits for a particular process. In modern machining industries the focus is mainly on the achievement of high quality, in terms of work piece dimensional accuracy, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase in the performance of the product with reduced environmental impact [1]. Surface roughness plays an important role in many areas and is a factor of great importance in the evaluation of machining accuracy [2]. Increasing the yield and the quality of the machined parts are the vital challenges of metal-based industry, so there has been enhanced interest in monitoring all aspects of the machining process. Surface finish also is a significant parameter in manufacturing engineering. It is that parameter which could influence the performance of mechanical parts and the production costs. So, while selecting any procedure for machining the surface finish should be achieved high quality. The lowest value of surface roughness gives the best surface finish [3], but besides, it should meet with all end conditions or requirements of production.

II. MATERIAL AND METHODS

For this experiment manually operated grinding machine was used, it was manufactured by Guru Arjan Machine Tool, Faridabad. General specification of this machine is given as under:
Working surface of the table = 225x350 mm
Maximum height from the table to grinding wheel = 275 mm
Vertical feed graduation = 0.01 mm
Cross feed graduation = 0.05 mm
Spindle speed = 2800 rpm
Size of Grinding wheel (Dia x Width x bore) = 200x13x31.75mm
Electric motor = 3 phase, 1 HP
Wheel balancing stand = one

Fig. 1 Grinding Machine

A. Work Piece material

The work piece material selected for experiment was High Carbon High Chromium (AISI D3). The chemical and physical properties are given in table 1.and Table 2.respectively

Fig. 2 work piece used for experiment.

TABLE 1
CHEMICAL COMPOSITION OF AISI D3

Element	C	S	P	Mn
%	2.02	0.026	0.028	0.59
Element	Si	Cr	V	W
%	0.28	11.14	0.021	0.07

TABLE 2
PHYSICAL PROPERTIES OF AISI D3

Physical Properties	**Value**
Density	7.7x1000 kg/m^3
Tensile strength	640-2000MPa
Elastic modulus	190-210 GPa
Hardness (HRC)	58
Poisson's Ratio	0.27-0.30

B. Grinding Wheel details

There are two main material types for grinding wheels: Aluminium Oxide and Silicon Carbide. Aluminium Oxide is used to grind materials such as hard steel, wrought iron and tough bronze. These materials are considered to have a high tensile strength. Depending on the purity factor, it can also be used to grind cast iron as well as satellite, which is used in dies and gages. Aluminium Oxide it the most common abrasive used in grinding wheels [4].

The size of wheel is 200 mm OD x 20 mm width x 31.75 mm ID with speed of 3000 rpm.

Details of wheels are given below:

TABLE 3
WHEEL SPECIFICATIONS

Type	Material	Colour
38A46-54K5V20	(Al_2O_3)	Black
8AP46-60K6V13T	(Al_2O_3)	Pink
38A46-20KV1	(Al_2O_3)	Pink

Fig. 3 Grinding Wheels used as cutting tool

C. Taguchi Method

In this experimental work, Taguchi approach has been used to design the experimental parameters. This Taguchi approach has reduced the number of experiments required to obtain necessary data for optimization of parameters with the use of Design of Expert (DOE). Therefore, after DOE using DOE and Taguchi approach has become a much more attractive tool for those who want optimization of any system. A total no of three parameters namely Grain Size, Depth of cut and feed were chosen for the controlling parameters, and each parameter is designed to have three levels, namely small, medium, and large, denoted by A, B and C, as shown in the Table 1.Mean while, a L9 Orthogonal array table is used to conduct the experiments. This array table has 3 column and 9 rows as shown in Table 3. Therefore only 9 experiments are needed to perform the entire machining parameter space using the L9 orthogonal array. To obtain a more accurate result, each combination of experiments was repeated three times.

TABLE 4
MACHINING PARAMETERS AND THEIR LEVELS

Control Parameters	**Level 1**	**Level 2**	**Level 3**
Grain Size (mesh)	4620	4660	4654
Depth of Cut (mm)	0.40	0.80	0.12
Cross Feed (mm/rev)	0.3	0.6	0.9

D. Orthogonal array

An appropriate orthogonal array (OA) depends on the total degrees of freedom of control parameters. Degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. In this study, since each parameter has three levels therefore, the total degrees of freedom (DOF) for the parameters are equal to 8. Basically, the degrees of freedom for the OA should be greater than or at least equal to those for the process parameters. The standard L9 orthogonal array has 3 level columns with 8 DOF. Therefore, an L9 orthogonal array with four columns and nine rows was appropriate and used in this study [7]. The experimental layout for the injection moulding parameters using the L9 OA is shown in Table.5; each row of this table represents an experiment with different combination of parameters and their levels, obtained by using Minitab 17

TABLE 5
EXPERIMENTAL LAYOUT FOR L9 ORTHOGONAL ARRAY

Grain Size	Depth of Cut	Cross Feed
M(mesh)	mm	mm/rev
1	1	1
1	2	2
1	3	3
2	1	3
2	2	1
2	3	2
3	1	2
3	2	3
3	3	1

E. Surface Roughness

The quality of machined surface is characteristics by the accuracy of manufacture with respect to the dimensions specified by the designer. Every machining operation leaves characteristic evidence on the machined surface. This evidence in the form of finely spaced micro irregularities left by the cutting tool. Each type of cutting tool or wheel leaves its own individual pattern which therefore can be identified. This pattern is known as surface finish or surface roughness. Fig.4 shows the example of the pattern on the work piece.

The surface roughness test was done by using Mitutoyo surface roughness tester 'Surftest SJ 301' was used. The probe was adjusted to measure the Ra value. The probe was moved a distance of 3mm.

Fig. 4 surface roughness test

III.RESULT AND DISCUSSION

TABLE 6
EXPERIMENTAL DATA WITH SURFACE ROUGHNESS AND S/N RATIO

S. No	Grain Size	Depth of Cut	Cross Feed	Surface Rough- -ness	S/N Ratio
1	4620	0.40	0.3	1.87	-5.43683
2	4620	0.80	0.6	2.41	-7.64034
3	4620	0.12	0.9	1.57	-3.91799
4	4660	0.40	0.9	1.67	-4.45433
5	4660	0.80	0.3	2.06	-6.27734
6	4660	0.12	0.6	0.74	2.61537
7	4654	0.40	0.6	0.97	0.26457
8	4654	0.80	0.9	1.59	-4.02794
9	4654	0.12	0.3	0.87	1.20961

TABLE 7
RESPONSE TABLE FOR SIGNAL TO NOISE RATIO

Level	Grain Size	Depth of Cut	Cross feed
1	-5.66506	-0.03100	-3.50152
2	-0.85125	-3.20887	-1.58680
3	-2.70544	-5.98188	-4.13342
Delta	4.81380	5.95087	2.54662
Rank	2	1	3

Table.7 indicates that for surface roughness the parameter that had the most influences feed with delta value of (2.546), followed by depth of cut (5.950) and Grain size (4.81).

TABLE 8
RESPONSE TABLE FOR MEANS

Level	Grain Size	Depth of Cut	Cross feed
1	1.950	1.060	1.600
2	1.143	1.503	1.373
3	1.490	2.020	1.610
Delta	0.807	0.960	0.237
Rank	2	1	3

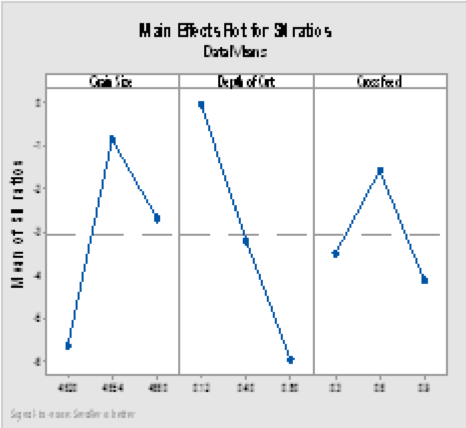

Fig. 5 Main effect plot for S/N ratio

Response Graphs for S/N values for Surface Roughness.

1. Medium Level for Grain Size, A_2 = 4654 mesh indicated as the optimum situation in terms of S/N values
2. Lower Level for Depth of cut, B_1 = 0.12 mm indicated as the optimum situation in terms of S/N values
3. Medium Level for Cross feed, C_2 = 0.6 mm/rev indicated as the optimum situation in terms of S/N values

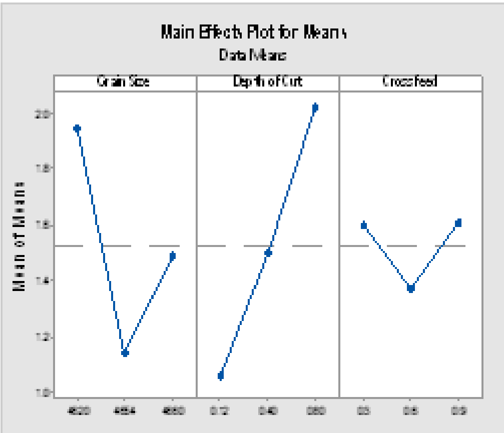

Fig. 6 Main effect plot for means

Response Graphs for Means

1. Medium Level for Grain Size, A_2 = 4654 Ra indicated as the optimum situation in terms of Surface Roughness values.
2. Lower Level for Depth of cut, B_1 = 0.12 mm indicated as the optimum situation in terms of Surface Roughness values.
3. Medium Level for Cross feed, C_2 = 0.6 mm/rev indicated as the optimum situation in terms of Surface Roughness values

A. The Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is the statistical tool applied to the results of the experiment to determine the percentage of contribution for each factors. Investigation of ANOVA table for a given analysis helps to determine which of the factors need control and which factor does not have need to control. when the optimum condition is determined, it is usually easy practice to run a confirmation experiment. In case of fractional factorial only some of the tests of full factorial are conducted. The analysis of the partial experiment must include an analysis of confidence that can be placed in the results. This technique does not directly analyze the data, but rather determines the variability (variance) of the data. Analysis provides the variance of controllable and noise factors. By understanding the source and magnitude of variance, robust operating conditions can be predicted.

Analysis of Variance (ANOVA) using MINITAB 17 software was performed to determine the contribution (in percentage) of the process parameters on the output responses.

Statistically, there is a tool called the F-test named after Fisher [8] to see which process parameters have a significant effect on the performance characteristic. Usually larger the F-value, greater the effect on the performance characteristic due to the change of the process parameter

B. Analysis of the S/N ratio

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value for the output characteristic. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available depending on type of characteristic: lower-the-better, nominal the-better and the higher-the-better. In this experiment, lower-the-better performance characteristic is considered to obtain minimum surface roughness. The experimental results for surface roughness and the corresponding S/N ratios are shown in Table 6.

For lower-the-better:

$$\text{S/N Ratio} = -10\times \text{Log}_{10} (\sum (y^2)/n)$$

TABLE 9
ANALYSIS OF VARIONCE (ANOVA) RESULT FOR ROUGHNESS FOR GRINDING

Source	DF	Adj.SS	Adj.MS	F-Value	P-Value
Grain Size	2	0.98249	0.49124	10.46	0.087
Depth of Cut	2	1.38509	0.69254	14.75	0.063
Cross feed	2	0.10749	0.05374	1.14	0.466
Error	2	0.09389	0.04694		
Total	8	2.56896			

From the table.9, it is clear that Grain Size and Depth of Cut are most significant process parameters as their F- values are greater than P- values for the output response where as other process parameter Cross feed is least significant as its F value is little more than P value as compared Grain size and Depth of Cut.

Regression Equation:

Surface Roughness =

1.5278 + 0.422 Grain Size_4620 -
0.384 Grain Size_4654 - 0.038 Grain Size_4660 -
0.468 Depth of Cut_0.12 - 0.024 Depth of Cut_0.40
+ 0.492 Depth of Cut_0.80 + 0.072 Cross feed_0.3 -
0.154 Cross feed_0.6 + 0.082 Cross feed_0.9

The formed equation was validated by tests and the error between the theoretical and actual value was negligible.

IV. CONCLUSIONS

The study discusses about the application of Taguchi method and ANOVA to investigate the effect of process parameters on surface roughness. From the analysis of the results obtained following conclusion can be drawn:

- Statistically designed experiments based on Taguchi method are performed using L9 orthogonal array to analyze surface roughness. The results obtained from analysis of S/N Ratio and ANOVA were in close agreement.
- Optimal parameters for surface roughness the optimal parameters found were Grain Size = 4654 mesh, Depth of Cut = 0.12 mm, Cross feed = 0.6 mm/rev,
- Depth of Cut and Grain Size are most significant process parameters while cross feed is least significant as compared to Grain Size and Depth of Cut.

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