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OPTIMIZATION OF SURFACE GRINDING PROCESS PARAMETERS FOR AISI D2 STEEL

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ABSTRACT
In grinding process, Surface quality and metal removal rate are the two important performance characteristics to be consider. In this paper, Taguchi L9 orthogonal array optimization method has been used to determine the optimum machining parameters in Surface grinding process operation on AISI D2 steel. The parameters considered in this paper are grinding wheel abrasive grain size, wheel speed, table speed and depth of cut. Empirical models are developed for surface roughness and metal removal rate by considering above parameters as control factors. Optimum machining parameters leading to maximum metal removal rate and minimum surface roughness has been determined by using Taguchi L9 orthogonal array method and the adequacy of the developed model is tested with analysis of variance (ANNOVA). The experiment has been conducted on special purpose grinding machine. The developed model can be used by the different manufacturing firms for the production of surface grinding machine for hardened steel. They can select appropriate combination of machining parameters to achieve an optimal metal removal rate (MRR) and surface roughness (Ra). The results were further validated by conducting confirmation experiments.

KEYWORDS: Metal removal rate, Surface grinding, Surface roughness, Taguchi Optimization.

INTRODUCTION
The surface quality produced in surface grinding is influenced by various parameters such as wheel parameters – i. 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.[1]

The present paper takes the following input processes parameters viz. wheel grit size, spindle speed, table speed and depth of cut. The main objective of this paper is to show how our knowledge on grinding process can be used to predict the grinding behaviour and achieve optimal operating processes parameters. The knowledge is mainly in the form of physical and empirical models which describe various aspects of grinding process. The main objective in any machining process is to lessen the surface roughness (Ra). In order to optimize these values, Taguchi method is used.

Taguchi's L9 orthogonal array: The effect of all the input parameters on the output responses have been studied using analysis of variance (ANOVA). The effect of variation in input parameters has been studied on the output responses. Plots of S/N ratio have been used to decide the best relationship between the responses and the input parameters, in other words, optimum set of input parameters for minimum surface roughness and maximum of metal removal rate are determined.

The main objectives of the paper are as follows:

1. To examine and optimize the grinding process parameters (wheel grit size, spindle speed, table speed and depth of cut) for the enhancement of the surface finish on AISI D2 steel so as to work out optimum set of input parameters for minimum surface roughness by using ANOVA method.
2. To confirm the validity of optimum set of input parameters obtained by conducting verification experiments.

LITERATURE SURVEY
Kumar et al. [2] aimed at finding the optimal material removal and effect of process parameters of cylindrical grinding machine by using Taguchi method. The experiment was designed using L-9 orthogonal array with three levels of each input variables. Analysis of variance (ANOVA) was used to investigate the effect of parameters. The authors found Analysis of variance (ANOVA) concluded that surface roughness is minimum at the 210 rpm, 0.11mm/rev feed, and 0.04mm depth of penetration.

Pal et al. [3] worked on optimization of grinding parameters for minimum surface roughness by Taguchi optimization technique. The authors conducted the experiments on a universal tool and cutter grinding machine with unusual grain sized aluminum oxide white grinding wheels, on different materials EN 24, EN 31 and Die steel. The work speed, material hardness and type of grinding wheel were chosen as input variables. The surface roughness was chosen as output parameter. An L9 orthogonal array was use to design the experiments. When the speed of work piece was changed it was found that the surface roughness decrease when speed was changed from 100 to 160 rpm and again decrease while speed further increased to 200 rpm. The authors also accomplished that when grinding wheel grain size change from G46 to G60, the surface roughness decreases, but at grain size G80 roughness increases considerably.

George et al. [4] considered the surface roughness and its prediction in cylindrical grinding process based on taguchi method of optimization. The material hardness, work piece speed, and depth of cut were preferred as input parameters and surface roughness was preferred as response factor. An L9 orthogonal array was used for designing the experiment. The experiments were conducted on En 24, EN 31, and EN 353 materials with a cylindrical grinding machine. Surface roughness was measured by Mitotoyo surf test SJ-400 roughness tester. When the work piece speed was greater than before the surface roughness decreased. The surface roughness was also decreased while the depth of cut was increased from 10 to 20 µm. The minimum surface roughness obtain was 0.47 µm at work piece speed of 120 rpm and when depth of cut was 20 µm.

EXPERIMENTAL STUDY

Workpiece Material:

The workpiece material selected for investigation is AISI D2 steel. AISI D2 steel is used for The workpiece material are used in dimensions of 68mm diameter and thickness 30 mm. The chemical composition of the AISI D2 steel is as follows:

Table 1: Chemical composition of aisi d2 steel.

C	1.40 - 1.60
Mn	0.60
Si	0.60
Co	1.00
Cr	11.00 - 13.00
Mo	0.17 - 1.20
V	1.10
P	0.03
Ni	0.30
Cu	0.25
S	0.03

Machining Process:

The grinding were performed on special purpose surface grinding machine which is having grinding wheel of size 200 x 25 x 31.7 ID. The material of grinding wheel is aluminium oxide. The experiments were carry out as per the orthogonal array. After that surface roughness for various combinations of parameters was measured using SURFCOM 480A tester and metal removal rate are calculated using the ratio of weight loss and machining time.

Design of Experiment:

The experiment was planned using Taguchi's orthogonal array in the design of experiments, which help in reducing the number of experiments and to find out significant factors in a shorter time period. Dr. Genichi Taguchi (1980) has given a standard way to utilize the DOE to improve the quality of product and process for the design and manufacturing and also reduces the cost. In this present work three levels at four parameter (factors) has been employed to predict the optimal values, as shown in Table 2. This levels are decided by trial experiments conducted considering one factor at a time. The L9 orthogonal array for four factors and three levels is used in the present investigation. This L9 orthogonal array is selected to check the interactions between the factors as shown in Table 3.

Table 2 : Parameters and their levels for experiment

Grinding parameters	**Symbol**	**Level**		
		1	**2**	**3**
Wheel grit size	W	24	36	46
Wheel speed	N	1650	2300	2950
Table speed	V	0.834	0.895	0.956
Depth of cut	D	0.025	0.050	0.075

Table 3:Orthogonal array of L9 showing 4 factor and 3 levels

Expt. No.	Factor 1	Factor 2	Factor 3	Factor 4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Measurement of Surface Roughness:

The surface roughness was checked using surface roughness testing machine. The surface roughness, Ra was measured in perpendicular to the cutting direction using a Surface Roughness tester. Surface roughness values are obtained from SURFCOM 480A Surface roughness tester for each experiment. Three reading are taken in each region, and the average of them were taken to minimize the error. Surface roughness (Ra) is use to record the output response. Figure 1. shows the SURFCOM 480A surface roughness tester which is used for measurement of surface roughness. The experimental results for surface roughness(Ra) obtained using Taguchi optimization technique are given in Table 4.

Fig 1: Surface roughness tester

Measurement of material removal rate:

The material removal rate can be found out by the difference of the initial reading and the final readings of the weight of the material of all samples of D2 steel. MRR can be calculated as the ratio of weight loss from the work piece to the machining time x gravity. The MRR value results for each experiment is given in Table 4.

Table 4: Surface roughness and material removal rate of each experiment

Expt. No.	SR (Ra) (µm)	MRR (mm^3/min)
1	0.666	25.478
2	0.557	26.619
3	0.547	43.695
4	0.916	53.602
5	0.654	19.987
6	0.576	55.251
7	0.652	33.132
8	0.450	59.315
9	0.930	11.929

RESULT AND DISCUSSION

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

Analysis of signal to noise (S/N) ratio:

In this section, impact of controllable factors is investigated using S/N ratio approach. A smaller value of surface roughness is usually required in metal machining. Therefore, the smaller the-better methodology of S/N ratio was in use for the aforesaid responses. Apart from 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 maximum S/N ratio. Ra and MRR values with the corresponding S/N ratios are given in the Table 5.

Table 5:surface roughness, mrr and their respective s/n ratio

Expt. No.	Ra	MRR	S/N ratio for Ra	S/N ratio for MRR
1	0.666	25.478	3.530	28.123
2	0.557	26.619	5.082	28.503
3	0.547	43.695	5.240	32.808
4	0.916	53.602	0.762	34.583
5	0.654	19.987	3.688	28.015
6	0.576	55.251	4.791	34.846

7	0.652	33.132	3.715	30.405
8	0.450	59.315	6.935	35.463
9	0.930	11.929	6.630	21.532

Signal-to-noise ratio response table:

Analysis of the influence of each control factor (W,N,V,D) on the surface roughness has been performed with a signal-to-noise ratio response table. Response tables of S/N ratio for Ra and MRR are shown in Table 6 and Table 7 respectively . It display 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 6: Response table mean S/N ratio for metal removal rate & significant interaction.

Level	Wheel	Spindle Speed	Table Speed	DOC
1	29.81	31.04 *	32.81 *	25.22
2	31.82 *	29.99	28.21	31.25
3	29.13	29.73	29.74	34.29*
Delta	2.68	1.31	4.60	9.06
Rank	3	4	2	1

(*indicate optimal level- larger is better)

Table 7: Response table mean S/N ratio for surface roughness & significant interaction.

Level	Wheel	Spindle Speed	Table Speed	DOC
1	0.5900 *	0.7447	0.5640*	0.7500
2	0.7153	0.5537 *	0.8010	0.5950 *
3	0.6773	0.6843	0.6177	0.6377
Delta	0.1253	0.1910	0.2370	0.1556
Rank	4	2	1	3

(* indicate optimal level – smaller is better)

Prediction of optimal solution:

The influence of each control factor can be clearly presented with response graphs (Fig 2 and 3). These figures reveal the level to be chosen for the ideal grinding 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.

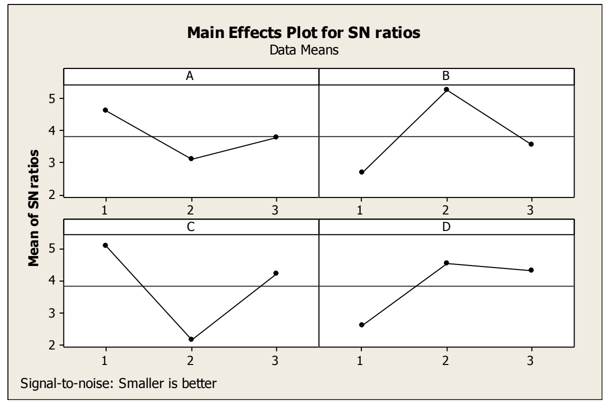

Fig 2: Main effect plot for S/N ratio for Ra

Source of variation	Degree of freedom (DF)	Sum of square (SS)	Mean square (MS)	F ratio	P value	% contribution
Grinding wheel	2	11.7	5.8	0.21	0.81	6.70
Spindle speed	2	2.9	1.4	0.05	0.95	1.655
Table speed	2	33.0	16.5	0.7	0.54	18.835
Depth of cut	2	127.66	63.83	8.06	0.02	72.865
Residual error		0.06				0.03
Total		175.2				100

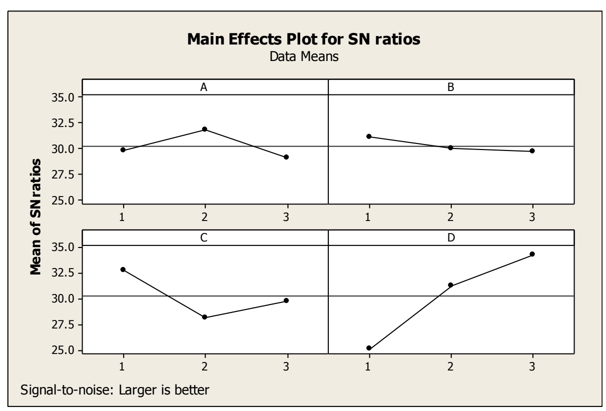

Fig 3: Main effect plot for S/N ratio for MRR

Analysis of variance (ANOVA):

The purpose of the ANOVA is to investigate which of the process parameters drastically affect the performance characteristics. This analysis provide the relative contribution of machining parameters in controlling the response of machining performance criteria i.e. surface roughness and MRR during D2 surface grinding. This is accomplished by separating the total unevenness of the S/N ratios, which is measured by the sum of the squared deviations from the total mean of the S/N ratio, into contributions by each of the process parameters and the error. Table 8 and 9 shows the results of analysis of variance for the S/N ratio of the surface roughness and MRR respectively.

Source	DF	SS	MS	F ratio	P Value	% contribution
Grinding wheel	2	3.56	1.78	0.39	0.717	10.48
Spindle speed	2	10.20	5.10	1.29	0.342	30.484
Table speed	2	13.56	6.78	2.00	0.216	40
Depth of cut	2	6.59	3.29	0.72	0.523	19.439
Residual error		0.01				0.03
Total		33.90				100

Table 8: Analysis of variance of s/n ratio for surface roughness.
Table 9:Analysis of variance of s/n ratio forMRR

Confirmation of experiment:
Predicted values of S/N ratio were investigated using conf1irmation test. The experimental values and predicted values are given in Table 10. Since the error between experimental and predicted value is under 10 % so the experimental work is said to be satisfactory.

Table 10 : Confirmation test result and comparison with predicted result as per mode

Output parameter	Experimental value	Predicted value	% error
SR (Ra) (μm)	0.438	0.459	4.79
MRR (mm^3/min)	60.231	61.102	7.76

CONCLUSIONS
Based on the analytical and experimental results obtained in this study following conclusions can be drawn.

1. The input parameters table speed, has a major effect on surface roughness, whereas depth of cut has a major effect on MRR of D2 steel.
2. The optimized parameters for minimum surface roughness are wheel grit size (46) grinding wheel speed (2300) , Table speed(0.834), depth of cut(0.050) and for maximum MRR are wheel git size (36) grinding wheel speed (1650) , Table speed(0.834), depth of cut(0.075)
3. The optimized minimum surface roughness is 0.438 μm and maximum MRR is 60.231

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