TO STUDY THE EFFECT OF GRINDING PARAMETERS ON SURFACE ROUGHNESS AND MATERIAL REMOVAL RATE OF CYLINDRICAL GRINDING OF HEAT TREATED EN 47 STEEL

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Abstract: *This research paper attempts to optimize the effect of input parameters to minimize surface roughness and maximize the material removal rate in cylindrically grinding of EN 47 steel material. Taguchi L18 (2)¹, (3)5 orthogonal array or mixed level of parameters have been applied to experimental design with the help of mini tab software. The result reveals that grain size and work speed are the most significant factors to influence material removal rate and surface roughness. The optimum set of input parameters for maximizing the material removal rate and optimum surface roughness have also been found*

Keywords: *Cylindrical grinding, Mini Tab, Anova analysis,S/N ratio, Surface roughness, Material removal rate.*

INTRODUCTION

Grinding is a material removal and surface generation process used to shape and finish components made of metals and other materials. Cylindrical grinding is one of the important metal cutting processused extensively in the finishing operations[1-5]. Grinding process is used to produce external shape of any object that may be straight, tapered, contoured. Surface roughness is used to control the quality of workpiece machining.In real life situation grinding is least understood of all machining process but it gives the better results under optimal conditions. The basic goal of grinding system is to accomplish the instruct shape, size and surface topology of the perfect product in a cost affected way[2]. Surface roughness plays an important role in describing the function of a surface. EN47 material are finding wide application in engineering Application, motor vehicle industry, crankshaft, spindles, steering knuckle, gears, pumps and application require high tensile strength and toughness[3].

George et al.[4] studied the cylindrical grinding machine with input parameters work speed, depth of cut and hardness material. The authors formulated an empirical relationship between the surface roughness values and the input parameters. The experiments were designed using L-9 orthogonal array with three levels of each input variables.The authors found that optimum Ra was 0.47 μm with hardness value of 64 hrc, work speed of 120 rpm and depth of cut 20μm.Thakor et al.[5] worked on optimization of grinding parameters for minimum surface roughness and maximum material removal rate by full factorial optimization technique. The authors found that optimum minimum surface roughness was 0.4246 μm with cutting fluid of water soluble oil, work speed of 120 rpm and depth of cut 500 μm. The authors concluded that optimum material removal rate was 0.0974 gm/sec with cutting fluid of water soluble oil,work speed of 120 rpm and depth of cut 500 μm.Yadav et al.[6]used response surface method for design of grinding parameters. The authors concluded that for SAE 8620 grade steel material the main parameters affecting the surface roughness were nozzle angle and flow rate.Singh et al.[7] aimed at finding the optimal surface roughness and effects of input parameters of cylindrical grinding using Taguchi L18 orthogonal array method. Surface roughness was selected as a response parameter. The experiment was designed using L18 orthogonal array. Analysis of variance was used to optimize the effect of parameters which revealed that the influence of depth of cut was significantly more than that of workspeed.

Kumar et al.[8] studied the surface roughness and its prediction in cylindrical grinding process parameters based on regression analysis of optimization. The authors developed a mathematical model using regression analysis. The authors concluded that depth of cut and table speed weresignificant parameters on surface roughness.Kadirgamaet al.[9] worked on surrogated modeling for predicting surface roughness and texture of surface when grinding of AISI 1042 carbon steel. The authors conducted the experiments on okumkoto CNC surface grinder withmedium grade alumina wheel having grain size of 60. Surface roughness was selected as a response parameter. The authors found that the optimal factors for minimum surface roughness were work speed 120 rpm, workpiece diameter 18 mm and depth of cut 20 µm. Mekalaet al.[10] aimed at finding the optimal material removal rate and effect of process parameters of cylindrical grinding machine by taguchi optimization technique. The authors conducted the experiments on cylindrical grinding machine. The experiments were designed using Taguchi L9 orthogonal array with 3 levels of each input variable. Material removal was selected as response parameter. The results were optimized by S/N ratio and Anova analysis. The authors concluded that the cutting speed was dominating parameter of cylindrical grinding.Pawanet al.[11]developed empirical model for surface roughness and material removal rate. The wheel speed, table speed and depth of cut were selected as input parameters. The authors found that optimum surface roughness was 1.2 µm with wheel speed of 850 rpm, table speed of 15 m/min and depth of cut 11.94 µm. The authors also found that optimal material removal rate was 31.82 gm/min with wheel speed of 850 rpm, table speed of 15 m/min and depth of cut 11.94 µm. Kiran et al.[12]developed empirical model using design of experiment by taguchi optimization technique. Surface roughness and material removal rate were selected as the response variables. The authors found that the optimal factors for minimum surface roughness were work speed 80 rpm, depth of cut 500 µm, no. of passes 6 and grinding wheel speed 1910 rpm. The authors found that the optimal factors for maximum removal rate were work speed 80 rpm, depth of cut 400 µm, no. of passes 3 and grinding wheel speed 1910 rpm. The authors concluded that the work speed was dominating parameter influencing surface roughness and no. of passes was dominating parameter influencing material removal rate.Ganesanet al.[13] proposed that in cylindrical grinding surface roughness was the important response and to achieve optimal process parameter. The authors predicted quality of surface roughness depends on size and shape of workpiece used.

The present research work is aimed to study the effect of different process parameters on the cylindrical grinding of EN 47 steel and to find optimum set of process parameters for minimum surface roughness and maximum material removal rate. The chemical composition of EN 47 is shown in table 1.

DESIGN OF EXPERIMENT

Mixed levels of input parameters (2Level and 3Level) have been applied on the experiment design. This set up was used for conducting the experiment on k -130 HMT grinding machine and Surface roughness and material removal rate are taken as response factors. The cylindrically rod of 22 mm diameter and 150 mm length was used for this experimentation work.

Table 1: Chemical composition of EN 47 material

Carbon	Silicon	manganese	Phosphorous	Chromium	Sulphur	Vanadium	Iron
0.542%	0.374%	0.634%	0.54%	0.826%	0.52%	0.19%	96.374%

Plan of experiment

The design of experiment was planned using taguchiL18 orthogonal array method.Input parameters are shown in table 2. For experimentation, mixed levels have been selected for each input parameter. The Taguchi L18 orthogonal array along with independent parameters and their selected levelsused for the experiment are shown in table 3.The grinding wheels used in the experiment are: Black aluminum oxide with grain size of 36, 46 and 60 (black aluminum oxide).

Table 2: The process input parameters and their levels

Input parameters	Level 1	Level 2	Level3
Wheel speed(rpm)	2200	2400	-
Work speed(rpm)	224	450	630
Grain size(mesh/inch)	36	46	60
Depth of cut(μm)	20	30	40
Flow rate(l/min)	2.53	7.13	11.53
No. of passes	3	4	5

Table3: design of experiment for grinding of EN 47

Exp. no	P wheel speed(rpm)	Q work speed(rpm)	R grain size(mesh/inch)	S depth of cut(μm)	T flow rate(l/min)	U no. of passes
1.	2200	224	46	20	2.53	3
2.	2200	224	60	30	7.13	4
3.	2200	224	36	40	11.53	5
4.	2200	450	46	20	7.13	4
5.	2200	450	60	30	11.53	5
6.	2200	450	36	40	2.53	3
7.	2200	630	46	30	2.53	5
8.	2200	630	60	40	7.13	3
9.	2200	630	36	20	11.53	4
10.	2400	224	46	40	11.53	4
11.	2400	224	60	20	2.53	5
12.	2400	224	36	30	7.13	3
13.	2400	450	46	30	11.53	3
14.	2400	450	60	40	2.53	4
15.	2400	450	36	20	7.13	5
16.	2400	630	46	40	7.13	5
17.	2400	630	60	20	11.53	3
18.	2400	630	36	30	2.53	4

Surface roughness value has beenmeasured by using MITUTOYO SJ-201 SURFACE roughness tester for experiments.

Material removal rate = (weights of jobs before machining –weights of jobs after machining)/machining time.Table 4 shows surface roughness, and material removal rates and their Signal to Noise(S/N) values.

Table 4: Result of surface roughness, material removal rate - S/N ratio value

Experiment no.	Surface roughness(μm)	S/N ratio	Material removal rate(g/min)	S/N ratio
1	0.7250	2.79324	1.61430	4.1597
2	0.8983	0.93157	1.85750	5.3786
3	0.5216	5.65325	0.66150	-3.5894
4	0.5030	5.96864	1.57000	3.9180
5	0.6983	3.11916	1.60000	4.0824
6	0.5016	5.99285	0.77186	-2.2492
7	0.5033	5.96346	1.58680	4.0104
8	0.6450	3.80881	2.11000	6.4856
9	0.4530	6.67804	0.39470	-8.0747
10	0.6983	3.11916	1.81400	5.1727
11	0.9014	0.90165	0.59400	-4.5243
12	0.4767	6.43510	1.43440	3.1334
13	0.6260	4.06851	3.53000	10.9555
14	0.7700	2.27019	1.16890	1.3555
15	0.3730	8.56582	0.33100	-9.6034
16	0.4900	6.19608	2.27100	7.1243
17	0.7560	2.42956	3.52300	10.9383
18	0.4183	7.57024	1.10896	0.8983

Table 5: Response table for S/N ratio for surface roughness by factor level

level	Wheel speed(rpm)	Work speed(rpm)	Grain size(mesh/inch)	Depth of cut(μm)	Flow rate(l/min)	No. of passes
1	4.568	3.306	6.849	4.589	4.249	4.255
2	4.617	4.998	4.685	4.681	5.318	4.456
3	-	5.474	2.243	4.507	4.211	5.067
Delta	0.050	2.169	4.606	0.175	1.106	0.812
Rank	6	2	1	5	3	4

Factors have been ranked on the basis of absolute difference in average level of S/N ratio between minimum and maximum value corresponding to each factor. The relative ranking of input parameters influencing the surface roughness was obtained by analysis of S/N data, so grain size is having the highest rank 1 and most significant parameter followed by work speed.

Table 6: Analysis of Variance for SN ratio for surface roughness

Source of variation	d.o.f	Sum of square	Mean square	f-ratio	P - value	P.C
Wheel speed(rpm)	1	0.0111	0.0111	0.03	0.861	0.01
Work speed(rpm)	2	15.5861	7.7931	23.58	0.001	17.66
Grain size(mesh/inch)	2	63.7149	31.8574	96.40	0.000	72.18
Depth of cut(μm)	2	0.0916	0.0458	0.14	0.873	0.10
Flow rate(l/min)	2	4.7368	2.3684	7.17	0.026	5.37
No. of passes	2	2.1445	1.0722	3.24	0.111	2.43
Residual error	6	1.9828	0.3305			2.25
Total	17	88.2678				

d.o.f= degree of freedom, p.c =percentage contribution

The percentage contribution has been calculated for all input parameters. At 5% level of confidence, $F_{0.05,2,6}$ is **5.14** and $F_{0.05,1,6}$is **5.99**. It is clearly found that grain size is the most significant parameter. From percentage contribution it is found that work speed and flow rate are also significant parameters.

Table 7: response table for S/N ratio for material removal rate by factor level

Level	Wheel speed(rpm)	Work speed(rpm)	Grain size(mesh/inch)	Depth of cut (µm)	Flow rate(l/min)	No. of passes
1	1.5691	1.6218	-3.2488	-0.5311	0.6072	5.5705
2	2.8270	1.4098	5.8901	4.7419	2.7394	1.4402
3	-	3.5625	3.9527	2.3833	3.2475	-0.4167
Delta	1.2579	2.1527	9.1389	5.2729	2.6403	5.9872
Rank	6	5	1	3	4	2

Factors have been ranked on the basis of absolute difference in average level of S/N ratio between minimum and maximum value corresponding to each factor. The relative ranking of input parameters influencing material removal rate was obtained by analysis of S/N data, so grain size is having the highest rank 1 and most significant parameter followed by no. of passes
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Table 8: Analysis of variance for SN ratio for material removal rate

Source of variation	d.o.f	Sum of square	Mean Square	f- ratio	Percentage contribution
Wheel speed(rpm)	1	6.723	6.723	0.9566	1.70%
Work speed(rpm)	2	16.503	8.2515	1.174	2.87%
Grain size(mesh/inch)	2	281.953	140.9765	20.05	49.08%
Depth of cut(µm)	2	91.73	45.865	6.5258	15.97%
No. of passes	2	112.277	56.1395	7.987	19.544%
Flow rate(l/min)	2	23.12	11.56	1.6448	4.025%
Error	6	42.169	4.6854		7.34%
Total	17	574.475			

The percentage contribution has been calculated for all input parameters. At 5% level of confidence,$F_{0.05,2,6}$is**5.14** and $F_{0.05,1,6}$ is **5.99**. It is clearly found that **5.14<20.05,** thus grain size is the most significant parameter.From percentage contribution it is found thatdepth of cut and no. of passes are also significant parameters.

RESULT AND DISCUSSION

A larger S/N ratio is used for optimization of input parameters for surface roughness and higher is better characteristic that is used for metal removal rate.

Main effect plot for surface roughness

1. The plot of S/N ratio of surface roughness for wheel speed is shown in figure 1. From figure it is clearly indicated that the wheel

speed does not have any effect on surface roughness.

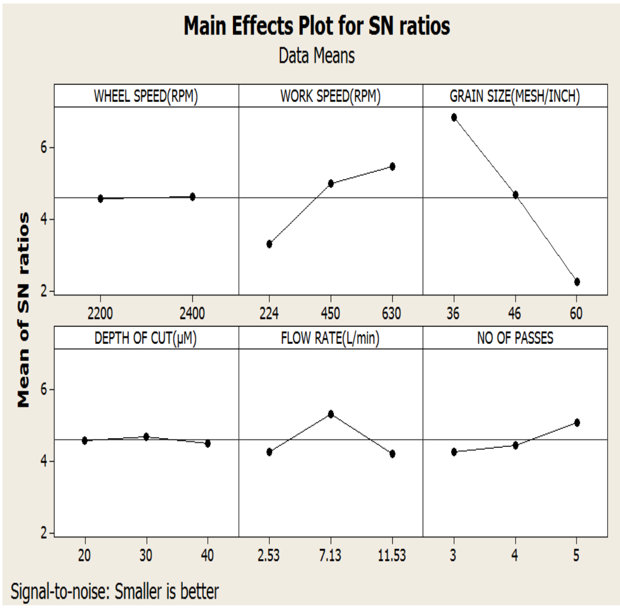

Figure 1: main effect plot of S/N ratio for surface roughness

2.Figure 1 shows that the S/N ratio increases linearly when work speed increases from 224rpm to 450rpm, S/N slightly increases when work speed further increasesfrom 450rpm to 630rpm, thus best finish is observed at 3rd level of Wheel speed i.e. 630 rpm.

3.The S/N ratio decreases linearly when grain size changed from 36(black) to 46(black),S/N ratio further decreases when grain size is changed from 46(black) to 60(black). Therefore optimal surface roughness is observed at 1stlevel of grain size i.e. 36mesh/inch (black).

4. From figure, it is observed that S/N ratio is slightly increases when depth of cut increases from 20μm to 30μm, S/N ratio decreases when depth of cut further increases from 30μm to 40μm. Therefore surface roughness is better with depth of cut 30 μm.

5. From figure 1, it is observed that the S/N ratio increases when flow rate increases from 2.53ml/min to 7.13ml/min, S/N ratio decreases when flow rate further increases from 7.13 l/min to 11.53 l/min. The S/N is higher at flow rate of 7.13 L/min which means it is optimum level of flow rate of 7.13L/min.

6. The S/N ratio remains almost constant when no. of passes changes from 3 to 4. But the value of S/N increases when no. of passes changes from 4 to 5. Therefore S/N is better with no. of passes of 5.

Main effect plot for Material Removal Rate

1. The S/N ratio is higher for wheel speed of 2400 rpm and it increases when wheel speed is changed from 2200 rpm to 2400 rpm. Thus it is observed that 2400 rpm is the optimum value of wheel speed for maximum material removal rate.

2. From figure 2 it is observed that S/N ratio slightly decreases when the work speed increases from 224 rpm to 450 rpm and

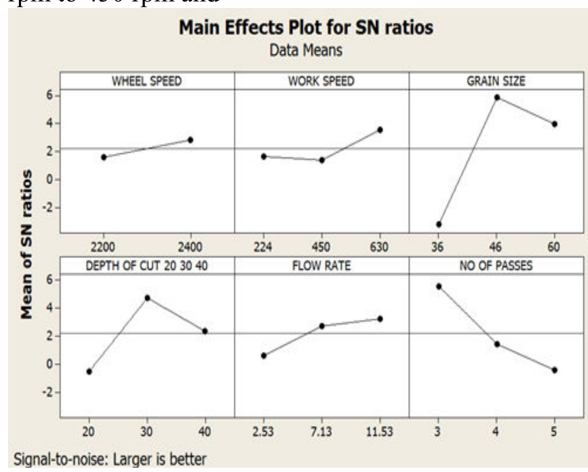

Figure 2: main effect plot of S/N ratio for Material removal rate.

linearlyincreases when work speed increases from 450 rpm to 630 rpm. It is observed that 630 rpm is optimum value of work speed for maximummaterial removal rate.

3. Effect of grain size on S/N ratio is shown in figure 2.S/N ratio suddenly increases when the grain size changesfrom 36b mesh/inch to 46b mesh/inch and decreases when the grain size changes from 46 (mesh/inch) to 60(mesh/inch). It is observed that 46b (mesh/inch) is the optimal value of grain size for maximum material removal rate. Grain size is the most significant parameter for maximum material removal rate.

4.S/N ratio is higher at depth of cut of 30μm which will give maximum material removal rate. It is observed that 30 μm is optimal value of depth of cut for maximum material removal rate.

5.S/N ratio linearly increases when the flow rate increases from 2.53L/min to 7.13L/minand S/N ratio further increases with increasing flow rate from 7.13L/min to 11.53 L/min. It is observed that flow rate 11.53 L/min is optimum value for maximum material removal rate.

6. S/N ratio suddenly decreases when we change no. of passes from 3 to 4 and again decreases S/N ratio when no. of passes change from 4 to 5. It is observed

that no. of passes 3 is optimum value for maximum material removal rate.
The optimum value of input parameters for surface roughness and material removal rate are shown in table 9.

Table 9: optimum value of surface roughness and material removal rate

Input parameters	Surface roughness	Material removal rate
Wheel speed	2400 rpm	2400 rpm
Work speed	630 rpm	630 rpm
Grain size	36 Aluminum black	46 Aluminum black
Depth of cut	30μm	30μm
Flow rate	7.13L/min	11.53L/min
Number of passes	5	3

6. CONCLUSION

This research work has discussed analysis of S/N ratio and Anova analysis approach for optimization of response parameters such as surface roughness and material removal rate in the grinding of EN47 material. The conclusions drawn from the analysis of results are as follows:

1. It has been found that Grain size and work speeds aresignificant parameters for EN 47 material. To achieve minimum surface roughness for EN47 material, employ grain size 36black aluminum oxide, wheel speed 2400 rpm, work speed 630 rpm, flow rate 7.53 L/min and depth of cut 30 μm.
2. The variables like wheel speed, depth of cut, and no. of passes are not significant parameters in case of surface roughness.
3. Moderate flow rate of cutting fluid(7.13L/min) oil which gives better surface finish and large decreases of surface roughness observed in, when grain size (mesh/inch) changed from 36b to 60b(mesh/inch).
5. To achieve maximummaterial removal rate, set the input parameters as moderate depth of cut(30μm), higher flow rate of cutting fluid (11.53L/min), grain size (46b mesh/inch), no. of passes(3)
6. As the work speed increases, the rubbing of grain also increases. Hence the material removal rate also increases.
7. Taguchi optimization and S/N data revealed that grain size is themost significant parameter influencing low RA and higher material removal rate.

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