RESEARCH ARTICLE OPEN ACCESS

Experimental Analysis & Optimization of Cylindirical Grinding Process Parameters on Surface Roughness of En15AM Steel

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ABSTRACT
As per the modern Industrial requirements, higher surface finish mechanical components and mating parts with close limits and tolerances, is one of the most important requirement. Abrasive machining processes are generally the last operations performed on manufactured products for higher surface finishing and for fine or small scale material removal. Higher surface finish and high rate of removal can be obtained if a large number of grains act together. This is accomplished by using bonded abrasives as in grinding wheel or by modern machining processes. In the present study, Taguchi method or Design of experiments has been used to optimize the effect of cylindrical grinding parameters such as wheel speed (rpm), work speed, feed (mm/min.), depth of cut and cutting fluid on the surface roughness of EN15AM steel. Ground surface roughness measurements were carried out by Talysurf surface roughness tester. EN15AM steel has several industrial applications in manufacturing of engine shafts, connecting rods, spindles, studs, bolt, screws etc. The results indicated that grinding wheel speed, work piece speed, table feed rate and depth of cut were the significant factors for the surface roughness and material removal rate. Surface roughness is minimum at 2000 r.p.m. of grinding wheel speed , work piece speed 80 rpm, feed rate 275 mm/min. and 0.06 mm depth of cut.
Keywords-Cylindrical Grinding, Process parameters, Surface roughness measurement, Taguchi method, ANOVA methodology.

I. INTRODUCTION

Grinding is a small scale material removal surface finishing process operation in which the cutting tool is an individual abrasive grain of an irregular geometry and is spaced randomly along the periphery of the wheel. The average rake angle of the grains is highly negative, typically -60 degree or lower, consequently the shear angle are very low. The cutting speeds of grinding wheels at very high, typically on the order of 30 m/s. Grinding are the machining processes which improve surface quality and dimensional accuracy of work piece. [1]

There are various process parameters of a cylindrical grinding machine that include grinding wheel speed, work piece speed, table feed, depth of cut, material hardness, grinding wheel grain size, no. of passes and material removal rate. Work piece Speed and feed rate are very important factor because increasing the both speed and feed rate has negative impact on surface roughness but high material removal cause reduction in surface roughness. [2]

Surface roughness is one of the most important requirements in machining process, as it is considered an index of product quality. It measures the finer irregularities of the surface texture. Achieving the desired surface quality is critical for the functional behavior of a part. Surface roughness influences the performance of mechanical parts and their production costs because it affects factors such as friction, ease of holding lubricant, electrical and thermal conductivity, geometric tolerances and more. The ability of a manufacturing operation to produce a desired surface roughness depends on various parameters. The factors that influence surface roughness are machining parameters, tool and work piece material properties and cutting conditions. For example, in grinding operation the surface roughness depends on depth of cut, material hardness, work piece speed, grinding wheel grain size, no. of pass, material removal rate and grinding wheel speed and on the mechanical and other properties of the material being machined. Even small changes in any of the mentioned factors may have a significant effect on the produced surface. [3]

Therefore, it is important for the researchers to model and quantify the relationship between roughness and the parameters affecting its value. The determination of this relationship remains an open field of research, mainly because of the advances in machining and materials technology and the available modeling techniques. [4]

Grinding is traditionally a finishing process employed to apply high quality surfaces to a work piece. This was possible due to the increased number of cutting edges present on a grinding wheel over that of conventional single point cutting tools. The relationship between cutting condition and the surface finish of the work piece has been establish and verified through series of studies. Grinding wheel consist of power driven grinding wheel driven at the required speed and a bed with a fixture to guide and hold the work piece. The grinding head can be controlled to travel across the fixed work piece or the work piece can be moved whilst the grind head stay in fixed position. Grinding, as a complex machining process with large numbers of parameters influencing each other, can be considered as a process where the grinding wheel engage with the work piece at a high speed. To achieve better process control a model is required to predict and demonstrate the whole life cycle performance in relation to the process input parameters. [5]

With increase is in grinding wheel speed, table feed, and work piece speed showed improvement in surface roughness and material removal rate on En15AM steel [6].

The authors found that the depths of cut and work piece speeds are significant. Parameter work piece speed, Grinding wheel speed and table feed among these factors are found more significant whereas the depth of cut and number of passes are found less significant during grinding of EN15AM steel [7].

Temperature rise in grinding is an important consideration because it can adversely affect surface properties and casual residual stresses on the work piece. It is found from the previous researches that the use of pure oil decreases the grinding force, specific energy, and acoustic emission and roughness values. These characteristics result from the high lubricating power of pure oil, which decreases the friction and reduces the generation of heat in the grinding zone. Therefore, pure oil used as a grinding fluid to obtain high quality superficial dressing and lower tool wear is the best choice for industrial applications [8]

Cutting fluid like water soluble oil gives better surface finish than pure oil used because the water mixed oil has lesser viscosity and more flow rate which results smoothing action during grinding process on EN15AM steel [9]

II. OBJECTIVE OF PRESENT INVESTIGATION

To analyze the effect of cylindrical grinding process parameters like grinding wheel speed, work piece speed, table feed, depth of cut, conditions, and optimize for enhancement of surface finish and effect on surface roughness on EN15AM steel.

III. EXPERIMENTATION

The work piece material EN15AM selected as work piece material having diameter 30 mm and length 380 mm round bar was used. This steel is widely used in industrial application like engine shafts, spindles, connecting rods, studs, screws etc for its good mechanical properties. The chemical composition of EN15AM steel is shown in Table1. The round bar was cut into pieces each having approximate length of 380 mm. The work piece was turned to a diameter of 28.5 mm using centre lathe machine, and the work piece was divided into 3 equal parts of 126.7 mm each. The surface roughness of work piece was measured before grinding at each region with the help of Surface Roughness Tester shown in Figure 4.1. To minimize the error, three reading have been taken for each region. Average values of three readings were taken for record.

Table 1 Chemical Composition (in weight %)

C	Mn	Si	Ni	Mo	Cr	S	P
0.3 - 0.4	1.3 -1.7	0.25	......	……	......	0.12-0.20	0.06

After turning operation of work piece on centre lathe machine, the next step was grinding. GG-600 universal cylindrical grinding machine was used for the experimentation as shown in fig. 3.1. Process parameters like speed of work piece, grinding wheel speed, feed rate and depth of cut were used as input parameters. And other parameter, condition of grinding (wet condition) was kept constant. The surface roughness was taken as response. The work pieces prepared after grinding process are shown in fig.3.2.

Table 2 Assigned values of input machining parameters at different levels and their designation

Factor Designation	Parameters (units)	Levels and corresponding values of Machining parameter		
		Level 1	Level 2	Level 3
A	Grinding wheel Speed (rpm)	1800	1800	2000
B	Work piece spindle Speed (rpm)	80	155	324
C	Table feed (mm/min.)	100	175	275
D	Depth of cut (mm)	0.02	0.04	0.06

Assigned values of input machining parameters at different levels and their designation are shown in

Table 2. Taguchi design of experiment was used for optimizing the input parameters using L_{18} (2^1 x 3^3) orthogonal array which has been shown in Table 3

Fig. 3.1 G.G.-600 Universal Cylindrical grinding machine

Fig.3.2 Prepared Work pieces after cylindrical Grinding Process

Table 3Design Matrix of L_{18} (2^1 x 3^3) orthogonal array

Exp. No.	Grinder Speed (rpm)	Work piece speed(rpm)	Feed Rate (Mm/min.)	Depth of Cut (mm)
1	1800	80	100	0.02
2	1800	80	175	0.04
3	1800	80	275	0.06
4	1800	155	100	0.02
5	1800	155	175	0.04
6	1800	155	275	0.06
7	1800	324	100	0.04
8	1800	324	175	0.06
9	1800	324	275	0.02
10	2000	80	100	0.06
11	2000	80	175	0.02
12	2000	80	275	0.04
13	2000	155	100	0.04
14	2000	155	175	0.06
15	2000	155	275	0.02
16	2000	324	100	0.06
17	2000	324	175	0.02
18	2000	324	275	0.04

IV. RESULTS AND DISCUSSIONS

4.1 Surface roughness results : After cylindrical grinding, Surface roughness values at each region were measured by using Surftest-4, L.C.-0.1µm surface roughness tester .Three reading were taken on each region and the average of them was taken to minimize the error. Figure 4.1 shows the Surftest-4 surface roughness tester which was used for measurement of surface roughness. The experimental results for surface roughness obtained using Taguchi optimization technique are given in Table 4.

Figure 4.1 Mitutoyo - Surf test–4, L.C.-0.1µm surface roughness tester

4.2. Analysis of Variance: The results for surface roughness (SR) are analyzed using ANOVA in Minitab 17 software. As lower value of surface roughness is the requirement in experimentation so the criterion for evaluation "smaller is better" is used. The interaction plot for SN ratio is shown in figure 4.2.1. Table 5 summarizes the information of analysis of variance and case statistics for further interpretation.

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

ANOVA Table 5 for Surface roughness clearly indicates that the work piece speed, grinding wheel speed and feed rate is more influencing for surface roughness and depth of cut is least influencing for surface roughness .The percent contribution of all factors is shown in the form of bar chart in Figure 4.2.2 which indicates that grinding wheel speed contributes maximum 22.95 %, depth of cut contributes 18.40 %, work piece speed contributes 16.47 % and feed rate has least contribution about Response Table 6 for signal to noise ratio shows that, the grinding wheel speed, depth of cut, feed rate work piece speed has 1, 2, 3, 4 rank respectively.

Table 4 Experimental results for surface roughness

Exp. No.	Grinding wheel Speed (RPM)	Work piece speed (RPM)	Feed Rate (Mm/min)	Depth of Cut (mm)	Roughness (µm)
1	1800	80	100	0.02	2.73
2	1800	80	175	0.04	2.36
3	1800	80	275	0.06	2.22
4	1800	155	100	0.02	0.99
5	1800	155	175	0.04	2.57
6	1800	155	275	0.06	2.60
7	1800	324	100	0.04	1.78
8	1800	324	175	0.06	2.05
9	1800	324	275	0.02	2.22
10	2000	80	100	0.06	2.69
11	2000	80	175	0.02	2.27
12	2000	80	275	0.04	2.44
13	2000	155	100	0.04	2.57
14	2000	155	175	0.06	2.39
15	2000	155	275	0.02	2.74
16	2000	324	100	0.06	2.73
17	2000	324	175	0.02	2.36
18	2000	324	275	0.04	2.23

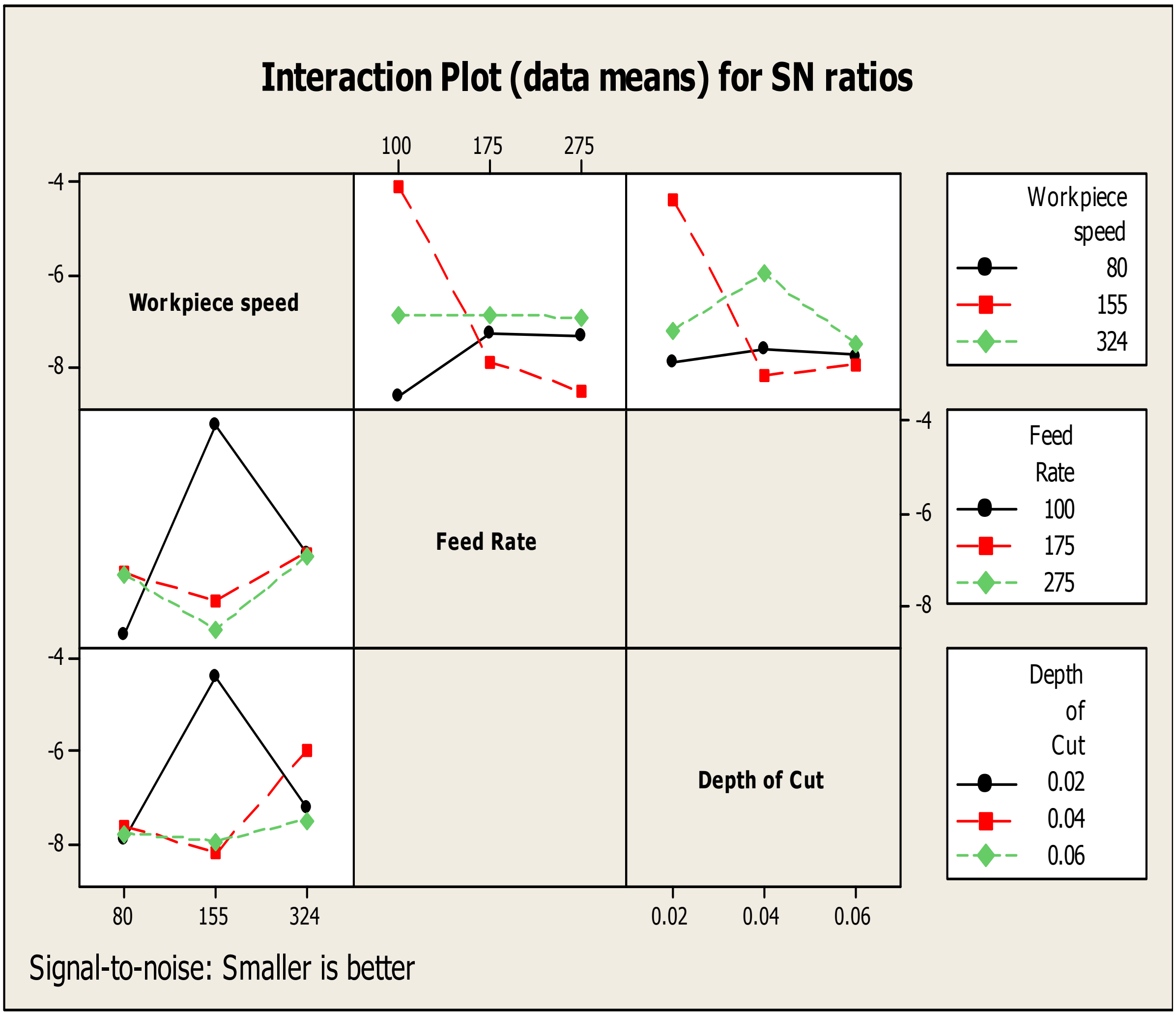

Figure 4.2.1 Interaction plot for SN ratios

Figure 4.2.1 Interaction plot for SN ratio clearly indicates that the value of surface finish is minimum at first level of work piece speed i.e. 80 rpm and table feed rate i.e. 100 mm/min., as the feed rate is increased to 175 mm/min., the surface finish of the work piece is also increased. While the table feed is increased to 275rpm, the surface finish of work piece is declined because as the feed rate increases the work piece doesn’t get proper time for process. At second level, the value of surface finish is higher at 155 rpm of wok piece speed and 100 mm/min. of table feed; further increase in the value of feed rate, surface roughness also decreases. At third level of work piece speed i.e. 324rpm, surface finish remains constant. Interaction of feed rate and depth of cut, it indicates that the value of surface finish is higher at 0.04 depths of cut and 100mm/min. Feed rate at first level, 0.02 depth of cut and 175 mm/min. feed rate at second level and 0.04 depth of cut and 275 mm/min. feed rate at second level. Interaction of work piece speed and feed rate indicates that the value of surface finish is higher at 155 rpm work piece speed and 100 mm/min table feed at first level, 324 rpm and 175 mm/min. At second level and 324 rpm and 275 mm/min. at third level. Interaction of work piece speed and depth of cut indicates that the surface finish is higher at 155 rpm work speed and 0.02mm depth of cut at first level, at second level surface finish is higher at 324 rpm of work piece speed and 0.04 mm depth of cut, at third level higher surface finish value obtained at 324 rpm of work piece speed.

Main effect plots for the surface roughness figure 4.2.3 indicates very clearly that the 2nd level of Grinding wheel speed i.e. 2000 rpm , 1st level of work piece speed i.e. 80 rpm , 3rd level of feed rate i.e. 275 Mm/min. and 3rd level of depth of cut i.e.0.06 mm are the optimum values for the minimum surface roughness. The level and the values at which surface roughness is minimum has been obtained are given in Table7.

Table 5 Analysis of Variance for means of SN ratio for Surface Roughness (Smaller is Better)

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
Grinding wheel Speed	1	16.481	16.481	16.481	30.86	0.0314	22.95
Work piece speed	2	11.83	11.85	5.925	11.09	0.0827	16.47
Feed rate	2	10.245	10.245	5.122	9.59	0.0944	14.46
Depth of cut	2	13.220	13.841	6.920	12.95	0.0717	18.40
Work piece Speed*Feed Rate	4	9.173	11.449	2.862	5.35	0.1636	12.77
Work piece Speed*Depth of Cut	4	9.792	9.792	2.432	4.55	0.1882	13.63
Residual Error	2	1.068	1.068	0.534			1.48
Total	17	71.808					100.00

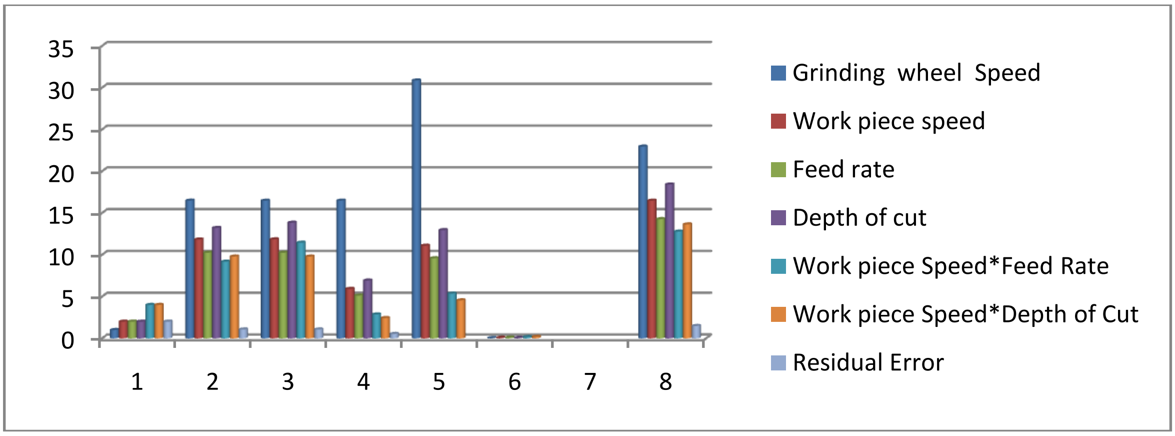

Figure 4.2.2 Percentage contributions of parameters towards surface roughness

Table 6 Response Table for Signal to Noise Ratios Smaller is better

Level	Grinding wheel Speed	Work piece speed	Feed rate	Depth of cut
1	-6.410	-7.762	-6.527	-6.483
2	-7.899	-6.822	-7.340	-7.256
3		-6.880	-7.597	-7.725
Delta	1.489	0.940	1.070	1.242
Rank	1	4	3	2

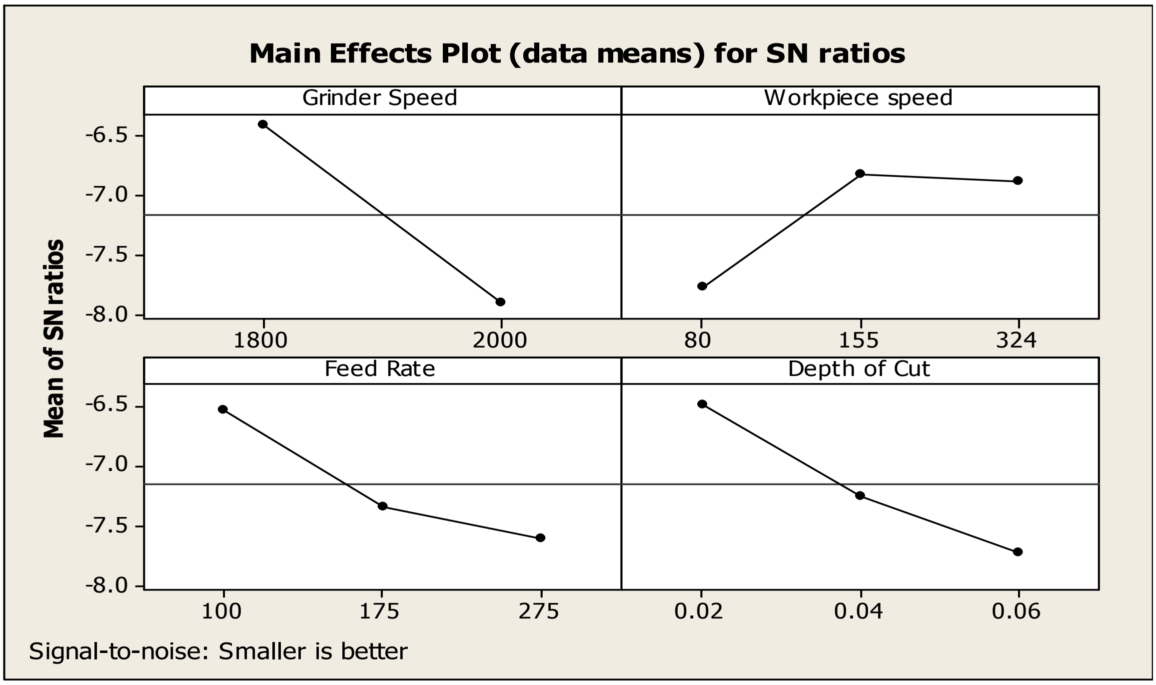

Figure 4.2.3 Main effects plot for means SN ratios (Surface Roughness)

Table 7 Levels and values of input parameters at minimum Surface Roughness

Factor	Grinding wheel Speed(rpm)	Work piece speed(rpm)	Feed rate (mm/min.)	Depth of cut (mm)
Level	3	1	3	3
Values	2000	80	275	0.06

4.3 Confirmation of experiment: Predicted values of means were investigated using conformation test .The experimental values and predicted values are given in the Table 8. Since the error between experimental and predicted value for surface roughness is 2.94 % it is clear from the literature that if percentage of error between the predicted data and the actual data is less than 10% then the experimental work is said to be satisfactory.

Table 8 Confirmation test result and comparison with predicted result as per model

Output Parameter	Predicted value	Exp. value	Error %
SR (μm)	1.02	0.99	2.94
		1.03	0.98
		1.01	0.98

CONCLUSION

Based on the analytical and experimental results obtained by Taguchi method, in this study following conclusions can be drawn:

1. The various input parameters of cylindrical grinding such as the work piece speed, grinding wheel speed and feed rate has more significant effect for surface roughness and depth of cut has least effect on surface roughness of EN15 AM steel.
2. The optimized parameters for minimum surface roughness are grinding wheel speed 2000 rpm, work piece speed 80 rpm, feed rate 275 mm/rev and depth of cut 0.06 mm.
3. The optimized minimum surface roughness is 0.99 µm which is about 76 % of initial value.

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