Evaluation of Surface Grinding Response Parameters of EN31 Alloy Steel

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Abstract. The purpose of this study is to understand the influence of processing parameters on surface roughness and material removal rate of EN31 Alloy Steel. Three input parameters are considered in this study, namely, the speed of the grinding wheel, number of passes and the depth of cut. The L16 orthogonal array design is used to analyse these process parameters. The results show that cutting depth and grinding wheel speed are the most effective parameters affecting material removal rate and cutting depth, and the number of passes is the most effective parameter affecting surface roughness. In addition, result showed that, the maximum MRR is 0.79051 g/sec and the surface roughness is 0.14000 μm. Therefore, it can be concluded that compared with other materials, cutting depth and wheel speed are less effective parameters, but compared with EN31 alloy steel, cutting depth and grinding wheel speed are the most effective parameters.

Keywords: Response Parameters, EN31 Alloy Steel, material removal rate, cutting depth, and surface roughness

1. Introduction

Surface grinding is one of the most commonly used processing techniques in the industry at present, and surface grinding is the best way to produce a good finish on a flat surface. George et al. [1], through Taguchi optimization technology, studied the grinding parameter of the minimum surface roughness. They experimented with different materials EN31, EN24 and die steel. Analysis of variance is used to optimize response parameters. They found that when the depth of cut changes, the surface roughness decreases from 10 microns to 20 microns. At workpiece speed (120) and cutting depth (20), the minimum surface roughness obtained is 0.47. However, Tao et al. [2] performed the investigation on the same material, but the selected input parameters were different, such as feed rate, abrasive size, grinding depth, and material removal rate. Surface integrity is preferred as the response parameter. They observed that the hardness is greatly affected by the depth of cut, and the material removal rate is most affected by the size of the abrasive. Padda et al. [3], considered the input parameters, such as wheel speed, depth of cut, and wheel particle size. In the course of the experiment, they noticed that stress will be generated when the grinding wheel is in contact with the workpiece, and observed that the speed of the grinding wheel is the most important factor in surface grinding. Lal et al. [4], taken the depth of cut, workpiece hardness and wheel type as input parameters, and observe that the output parameters are affected by the interface temperature of the tool and workpiece. In another study by Trung et al. [5], analyzed the input parameters of SUJ2 material, such as grinding wheel speed, cutting depth and
working speed. After analysis, they found that as the workpiece speed and volume fraction increase, the surface roughness value increases.

Demirl et al. [6] studied ASISI 1050 steel and regarded grinding force, grain size and depth of cut as input parameters. When using an 80 grain size grinding wheel to increase the depth of cut from 0.04 mm to .06 mm, the change in grinding force increased by 50%, and burns and cracks appeared on the machined surface. However, Vinay et al. [7] check AISI D3 steel on a surface grinder. The input parameters are drying and pool conditions, feed rate, depth of cut, and dressing depth. RSM is used to find the relative influence of input parameters on surface roughness. They pointed out that the surface finish obtained under dry grinding conditions is better than wet grinding conditions. Jejurkar et al. [8], performed an experiments on AISI 321 stainless steel on a surface grinder, considering such input parameters as working speed, feed rate and depth of cut. Taguchi method and analysis of variance were used to check the values from input parameters. They pointed out that speed is the parameter that has the most influence on MRR, but high MRR can be achieved at wheel speed (1150rpm), cutting speed (16m/min) and depth of cut (10.6 µm). In a study by Puerto et al. [9], the finishing operations of hard materials were checked to improve the minimum surface roughness and precision tolerances of F5229 steel. The input parameters are considered as grinding wheel dressing, grinding conditions, grinding force and radial wear of the grinding wheel. They concluded that under aggressive grinding conditions, rough grinding wheel topography will be produced. However, in an investigation by Patel et al. [10], the surface roughness of EN8 steel was checked. The preferred input parameters are wheel speed, depth of cut, wheel material, surface grinding and working speed, and different grinding wheels for cylindrical grinding. This method applies Taguchi's method, analysis of variance, and signal-to-noise ratio, and then they conclude that the material of the grinding wheel and the grade of the grinding wheel are the most important factors in the surface and cylindrical grinding process. Therefore, the main purpose of this article is to predict the grinding behavior and achieve the best operating process parameters. This study uses the following input process parameters: number of passes, depth of cut, and wheel speed.

2. Material and Method

EN31 steel alloy is used as the workpiece material. EN31 alloy steel is widely used in various industrial applications such as ball bearings and roller bearings, spinning tools, ball roller punches and dies. 16 flat steel bars of EN31 steel were selected as workpieces with a length of 100 mm, a width of 20 mm, and a thickness of 15 mm. As shown in Figure 1. The experiments were performed at Bhartiya Skill Development University, Jaipur. The range of input parameters for the selected machine shown in Table 1.
Table 1: Input Parameters

| Sr. No. | Input Parameters | Units | Range       |
|---------|------------------|-------|-------------|
| 1       | No. of Passes    | Nil   | 1-4         |
| 2       | Depth of Cut     | mm    | 0.01mm-1mm  |
| 3       | Wheel Speed      | Mm/Min| 375-150mm/Min |

2.1. Design of Experiments

Design of experiments is known as the technique of defining and investigating all possible conditions in an experimental involving multiple factors. This technique is also referred to as factorial design and design of experiments concepts have been in use since Sir Ronald A. Fisher's work in agricultural experimentation. Successfully to apply designed of experiments to determine optimum treatments of land for agriculture to achieve maximum yield by Ronald A. Fisher. In manufacturing process are consisting the controls factors, response factors and several noise factors. The following considerations for application of the technique

- Definition of quality
- Standardized DOE
- Loss function
- Signal to noise (S/N) ratio
- Robust design strategy

For present work L16 orthogonal array is used. Properties of L16 orthogonal array are as follow:

- No. of experiments = 16
- No. of levels = 4
- No. of factors = 3

Here we selected L16 OA means level 4 in Taguchi design Experiment because when we select L9 the nos. of workpiece are 9 means level 3 and when we select L16 the nos. of workpieces are 16 so with the level for output result would be more optimized but with the level 3 the nos. of workpiece is less than the level 4 so output result comparatively not more optimized with the level 4 so here we selected L16 OA in this experimental work. Most of the author selected the range of the parameters near to this range and depth of cut is selected maximum up to 1mm because above the 1mm the burning of metal started. The input parameter range and DOE are shown in Table 2 and 3.

Table 2: Input parameters range

| Control factors | Units  | Levels |
|-----------------|--------|--------|
|                 |        | I  | II | III | IV |
| No. of passes   | Nil    | 1  | 2  | 3   | 4  |
| Depth of Cut    | mm     | 0.02| 0.04| 0.06| 0.08|
| Wheel speed     | Mm/min | 375 | 750 | 1125| 1500|
Table 3: Design of experiment

| Run order | No. of passes | Depth of Cut | Wheel speed |
|-----------|--------------|--------------|-------------|
| 1         | 1            | 0.02         | 375         |
| 2         | 1            | 0.04         | 750         |
| 3         | 1            | 0.06         | 1125        |
| 4         | 1            | 0.08         | 1500        |
| 5         | 2            | 0.02         | 750         |
| 6         | 2            | 0.04         | 375         |
| 7         | 2            | 0.06         | 1500        |
| 8         | 2            | 0.08         | 1125        |
| 9         | 3            | 0.02         | 1125        |
| 10        | 3            | 0.04         | 1500        |
| 11        | 3            | 0.06         | 375         |
| 12        | 3            | 0.08         | 750         |
| 13        | 4            | 0.02         | 1500        |
| 14        | 4            | 0.04         | 1125        |
| 15        | 4            | 0.06         | 750         |
| 16        | 4            | 0.08         | 375         |

2.2. Measurement of Surface Roughness

Surface roughness is measured with the help of SURTRONIC S-128 surface roughness tester for each experiment as shown in Table 4.

2.3. Signal to Noise ratio

The logarithmic function used to optimize the process or product design, minimizing the changeability is called signal-to-noise ratio. To analysis the performance and optimized the process parameters Taguchi used S/N ratio and provide the optimum results. The three categories of S/N ratio generally used and the selection of one type of S/N ratio in among the three type of S/N ratio are depending on the nature of problem. The three types of S/N ratio are Nominal is better, smaller is better, larger is better. Smaller is better (S/N ratio) for surface roughness and larger is better (S/N ratio) for maximum material removal rate.

(a) Nominal is better

\[
\frac{S}{N} = 10 \log_2 \frac{\mu^2}{\sigma^2}
\]
(b) Smaller is better

\[ S_N = -10 \log \frac{1}{n} \left( \sum_{i=1}^{n} y_i^2 \right) \]  

(2)

(c) Larger is better

\[ S_N = -10 \log \frac{1}{n} \left( \sum_{i=1}^{n} \frac{1}{y_i^2} \right) \]  

(3)

Where

- \( \mu^2 \) = desired square of mean
- \( \sigma^2 \) = Variance of observation of replicated response variable.

Table 4 MRR and surface roughness value

| No. of experiments | No. of Passes (N) | Depth of cut (D) | Wheel speed (V) | Material Removal rate (MRR) | Surface roughness (Ra) |
|--------------------|-------------------|-----------------|-----------------|----------------------------|-----------------------|
| 1                  | 1                 | 0.02            | 375             | 0.41667                    | 0.22667               |
| 2                  | 1                 | 0.04            | 750             | 0.78740                    | 0.21000               |
| 3                  | 1                 | 0.06            | 1125            | 0.41841                    | 0.15333               |
| 4                  | 1                 | 0.08            | 1500            | 0.79051                    | 0.24667               |
| 5                  | 2                 | 0.02            | 750             | 0.11148                    | 0.22667               |
| 6                  | 2                 | 0.04            | 375             | 0.13514                    | 0.18667               |
| 7                  | 2                 | 0.06            | 1500            | 0.16667                    | 0.14667               |
| 8                  | 2                 | 0.08            | 1125            | 0.33223                    | 0.16667               |
| 9                  | 3                 | 0.02            | 1125            | 0.07937                    | 0.21000               |
| 10                 | 3                 | 0.04            | 1500            | 0.10672                    | 0.14000               |
| 11                 | 3                 | 0.06            | 375             | 0.20471                    | 0.19667               |
| 12                 | 3                 | 0.08            | 750             | 0.10549                    | 0.23667               |
| 13                 | 4                 | 0.02            | 1500            | 0.27397                    | 0.16667               |
| 14                 | 4                 | 0.04            | 1125            | 0.08224                    | 0.25667               |
| 15                 | 4                 | 0.06            | 750             | 0.07645                    | 0.34333               |
| 16                 | 4                 | 0.08            | 375             | 0.07692                    | 0.24000               |

3. Results and Discussion
The higher the signal to noise ratio in more favourable is the effect of the input variable on the output. The graph shows that the optimum value levels for best surface roughness (minimum) and MRR maximum. Table 5 shows the response table for signal to noise ratios (smaller is better) in which wheel speed is ranked 1 and Table 6 shows the response table for signal to noise ratios (larger is better) in which nos. of passes is ranked 1. In addition, the optimal value for material removal rate (MRR) is 0.79051 gram/sec obtained and the optimum machining parameters are number of passes 1, depth of
cut of 0.08 mm and 1500 rpm of wheel speed. When compared with the other materials depth of cut and wheel speed is less effective parameters but with the EN31 alloy steel depth of cut and wheel speed are most effective parameters. However with the increase in no of passes, decrease the depth of cut and increase the wheel speed surface roughness increases and material removal rate also decreases. However the minimum surface roughness obtain was 0.47 at workpiece speed (120), depth of cut (20) on ASISI 1050 steel but with the EN31 alloy steel maximum MRR 0.79051 gram/sec is obtain at depth of cut 0.08 mm, no of passes 1 and wheel speed 1500 rpm and minimum surface roughness surface roughness 0.14000 µm is obtain at 0.06 mm depth of cut, no of passes 3 and wheel speed 1500 rpm. Moreover, main effect plot of S/N ratio for surface roughness and MRR are shown in Figure 2 and 3 respectively.

| Table 5 Response Table for Signal to Noise Ratios (Smaller is Better) |
|-------------------|-----------------|-----------------|
| Level  | No. of passes  | Depth of cut  | Wheel speed    |
| 1     | 13.72          | 13.73          | 13.50          |
| 2     | 14.93          | 14.26          | 12.06          |
| 3     | 14.32          | 14.09          | 14.30          |
| 4     | 12.26          | 13.16          | 15.37          |
| Delta | 2.66           | 1.10           | 3.31           |
| Rank  | 2              | 3              | 1              |

| Table 6 Response Table for Signal to Noise Ratios (Larger is Better) |
|-------------------|-----------------|-----------------|
| Level  | No. of passes  | Depth of cut  | Wheel speed    |
| 1     | -4.823         | -14.978        | -15.261        |
| 2     | -15.394        | -15.149        | -15.750        |
| 3     | -18.689        | -14.810        | --15.211       |
| 4     | -19.389        | -13.357        | -12.071        |
| Delta | 14.566         | 1.791          | 3.679          |
| Rank  | 1              | 3              | 2              |

Figure 2 Response graphs for surface roughness
4. Conclusion

For EN31 steel following conclusion are analysed as follows:

For Material Removal Rate (MRR), depth of cut was the most effective parameter for EN31 alloy steel work material followed by grinding wheel speed, number of passes and depth of cut. So, to achieved the maximum material removal rate for EN31 alloy steel at high depth of cut 0.08 mm, moderate no. of passes 1 and high wheel speed 1500 rpm.

For Minimum surface roughness (Ra), no of passes was the most effective parameter for EN31 alloy steel work material followed by grinding wheel speed, number of passes and depth of cut. So, to achieved the minimum surface roughness for EN31 alloy steel moderate depth of cut 0.06 mm, No. of passes 3 and high wheel speed 1500 rpm.

Conflict of interest
None.

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