Investigations on the Effect of Radius Milling Process Parameters on Surface Roughness

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Abstract-- Present paper presents a study that investigates the effect of radius milling process parameters on the surface roughness of the EN 31 steel. The experimental plan is based on Taguchi's L9 orthogonal array with three factors and three levels for each variable. Nine experimental runs based on Taguchi L9 orthogonal array are performed and applied to determine an optimal radius milling process parameter combination. Surface roughness is selected as the quality targets. The experiments were conducted on EN 31 steel material on CNC vertical machine using carbide ball mill. The analysis of variance is employed to study the significance of each machining parameter. The results indicated that the feed rate with the contribution of 75.351% is the most important parameter affecting the surface roughness. The optimal combination of the parameters for radius milling process found to be is $\mathbf{A_1B_1C_1}$.

Key Words: ANOVA, EN 31 steel, L_9Orthogonal array, Optimization, Radius Milling, Surface Roughness, Taguchi Method.

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1 INTRODUCTION

Milling is the process of removing extra material from the work piece with a rotating multi point cutting tool known as milling cutter/mill. Milling is one of the basic machining processes which is widely used in manufacturing industries. The three primary parameters in any basic milling operation. spindle speed, feed rate, depth of cut are taken into consideration. EN 31 steel is one of the widely-used materials for various products such as ball and roller bearings, spinning tools, punches and dies which are often made by several cutting and finishing operations. EN 31 steel has high resisting nature against wear and can be used for components which are subjected to severe abrasion, wear or high surface loading. Owing to the inherent characteristics of EN31 steel such as high strength, hardness and good corrosion resistance, its machinability is poor and it often requires high speed for machining. Further, the quality of the machined surface is also relatively not up to the mark. Robust design is an engineering methodology for obtaining product and process conditions, which are minimally sensitive to various causes of variation to produce high quality products with low development and manufacturing costs. Taguchi's parameter design is an important tool for robust design, it offers a simple and systematic approach to optimize design for performance, quality and cost.

2 LITERATURE REVIEW

In past, a lot of work has been carried out to investigate the effect of radius milling process parameters on various performance parameters. Various machining processes were optimized by the researchers for improving the quality of the product.

Kothiyal et al. (2012) optimized the parameter for MRR using Taguchi methodology and ANOVA. The L_9 Orthogonal array (OA) is used in MINITAB 15 which shows the percentage contribution of each influencing factor on MRR. The material used for the experiment is (100 x 34 x 20 mm) blocks of aluminum cast heat-treatable alloy.

Akhyar et al. (2008) applied Taguchi optimization method to optimize the cutting parameters in turning Ti-6%Al-4% v extra low interstitial with coated and un coated cemented carbide tools under dry condition and high cutting speeds for improved surface finish. L_{27} orthogonal array including four factors such as cutting speed, feed rate, depth of cut and tool grades with three levels for each factor was used to identify optimal combination. ANOVA is used to determine the cutting speed and tool grade to be significant factors affecting the surface finish.

Thakkar et al. (2014) optimized process parameters for SR and MRR for SS 410 material. All experiments conducted on CNC turning and the output parameters MRR & SR are predicted by ANOVA.

Khan et al. (2015) studied the effect of WEDM process parameters on surface roughness. Taguchi's experimental design technique were used to conduct the experiment. The process parameters used were Pulse on time, pulse off time, Current. The material used for the experiment was EN 31 steel with dimensions of (200 mm × 40 mm × 10 mm). Nine experimental runs based on an L_9 Orthogonal array of Taguchi method are performed and it is subsequently applied to determine an optimal WEDM parameter setting. The analysis of variance (ANOVA) reveals that the Pulse OFF time is the most significant controlled factor for affecting the surface roughness.

Wahid et al. (2015) studied the effect of CNC milling machining parameters on the depth of pocket. The experiments were conducted using Taguchi's experimental design technique. The process parameters used were cutting speed, feed rate and depth of cut. The material used for the experiment is (410 x 250 x 30 mm) block of EN 31 Steel. Nine experiments were conducted based on L_9Orthogonal array to identify optimal combination. ANOVA is employed to study significance of each machining parameter on depth of pocket. They found spindle speed with the contribution of 41.52% is the most significant parameter affecting the depth of pocket.

Palanikumar et. al. (2008) studied the use of Taguchi and response surface methodologies for minimizing the surface roughness in machining Glass Fiber Reinforced Plastics (GFRP) with a Polycrystalline Diamond (PCD) tool. The experiments were conducted using Taguchi's experimental design technique. The cutting parameters used were cutting speed, feed and depth of cut. The effect of cutting parameters on surface roughness is evaluated and the optimum cutting condition for minimizing the surface roughness is determined. The experimental results revealed that the most significant machining parameter for surface roughness is feed followed by cutting speed.

3 EXPERIMENTAL PROCEDURE

3.1 Materials

EN 31 steel with dimension (200 mm × 40 mm × 10) is used in the present study as a base material. Machined EN 31 steel based on Taguchi's L9 OA is shown in fig. 1. The chemical composition of EN 31 steel presented in Table 1.

EN 31 Steel has high resisting nature against wear and can be used for components which are subjected to severe abrasion, wear or high surface loading.

Applications involving manufacture of ball and roller bearing, spinning tools, beading rolls, punches and dies.

Experimental setup of radius milling machine is shown in Fig. 2. The surface roughness values were measured by the surface roughness tester (model: SURFTEST, SV-2100; make: Mitutoyo, Japan)

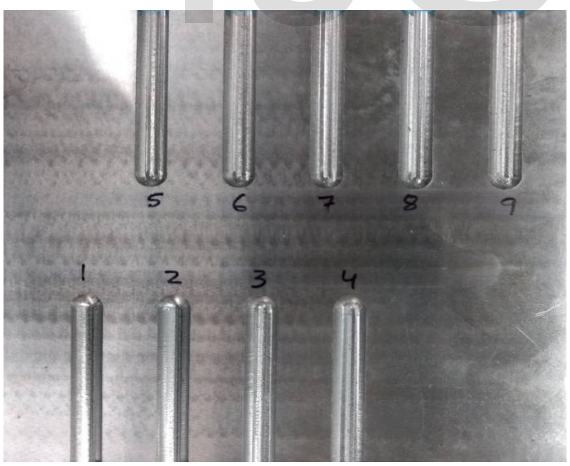

Fig 1. Machined EN 31 steel based on Taguchi's L_9 OA

TABLE 1. Material Composition of EN 31 Steel

Element	Concentration (% by weight)
Carbon	0.70 – 1.20
Silicon	0.10 – 0.35
Manganese	0.30 -0.35
Sulphur	0.050
Phosphorous	0.050
Chromium	1.0 -1.60

The experimental studies were performed on a vertical milling machine

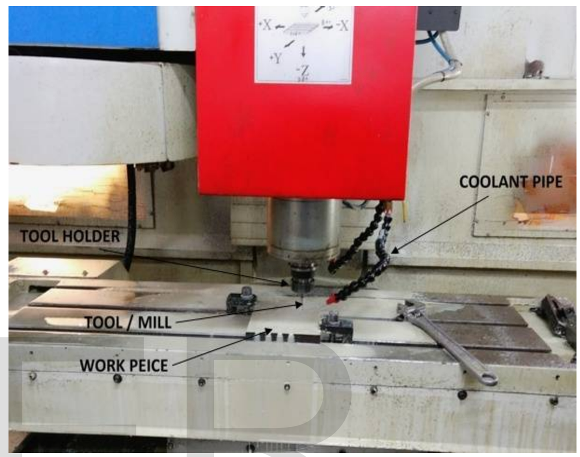

Fig. 2. Vertical milling machine

3.2 Experimental Design

In this study, Taguchi method, a powerful tool for parameter design of performance characteristics, was used to determine optimal machining parameters for minimum surface roughness in radius milling. In Taguchi method, process parameters which influence the products are separated into two main groups: control factors and noise factor. The control factors are used to select the best conditions for stability in design of manufacturing process, whereas the noise factors denote all factors that cause variation. Taguchi proposed to acquire the characteristic data by usingorthogonal arrays, and to analyze the performance measure from the data to decide the optimal process parameters. This method uses a special design of orthogonal arrays to study the entire parameter space with small number of experiments only, according to the Taguchi quality design concept, there are three categories of performance characteristics in the analysis of the S/N ratio: the lower-the better, the higher-the-better, and the nominal-the better. Regardless of the category of the performance characteristic, a larger S/N ratio corresponds to better performance characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed to identify the process parameters that are statistically significant. The lower the better criteria for the surface roughness was selected for obtaining optimum machining performance characteristics. S/N ratio is the ratio of mean to square deviation. Below given Eq. was employed for calculating S/N ratios for lower the better criteria.

$$\eta = -10 \log \left[\frac{1}{N \sum_{n}^{i=1} y_i}\right]$$

The experiments were conducted with three parameters having 3 levels. Nine experimental runs based on the orthogonal array L9 were carried out. Table 2 below shows three parameters, *i.e.* **spindle speed (A), feed rate (B), and depth of cut(C),** with three levels for each factor.

Also, Table 3 shows the nine cutting experimental runs according to the selected orthogonal table. After cutting, the values of surface roughness (*i.e.*, Ra (am)) were measured.

3.3 Design of Experiments (DOE) and Process Parameters

The DOE helps us for conducting experiments in a more systematic way. The process parameters with their levels are specified in table 2 below.

Table 2: Experimental factors and their levels

Factor	Symbol	Unit	Level-1	Level-2	Level-3
Spindle speed	A	rpm	1000	1500	2000
Feed rate	B	mm/min	500	750	1000
Depth of cut	C	mm	0.1	0.15	0.2

3.4 Orthogonal Array

Orthogonal array is a statistical method of defining parameters that converts test areas into factors and levels. It allows for the maximum number of main effects to be estimated in an orthogonal manner, with minimum number of runs in experiment, L9 orthogonal array used in the study is shown in tab

Table 3: Experimental plan based on L_9 Orthogonal array

Experiment No.	A (Spindle Speed)	B (Feed Rate)	C (Depth of Cut)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

TABLE 4: SURFACE ROUGHNESS VALUES AND CORRESPONDING S/N RATIOS

Exp. No	A	B	C	Ra(μm)	S/N ratio
1	1000	500	0.1	1.723	-4.725
2	1000	750	0.15	2.828	-9.029
3	1000	1000	0.2	3.869	-11.751
4	1500	500	0.2	2.750	-8.786
5	1500	750	0.1	2.905	-9.262
6	1500	1000	0.15	3.486	-10.846
7	2000	500	0.15	1.927	-5.697
8	2000	750	0.2	3.566	-11.043
9	2000	1000	0.1	3.543	-10.987

4 RESULTS AND DISCUSSION

The following sections describe the results of the present study and also present a discussion on the results.

The experimental results for the surface roughness along with corresponding S/N ratios are listed in Table 4. Typically, small values of surface roughness are desirable for good quality and accuracy in the machining operation. Thus, the data sequences have a "smaller- the-better characteristic" for surface roughness.

4.1 Analysis of Mean (ANOM)

In ANOM, mean value of the S/N ratio at each level of the process parameters is computed by taking arithmetic mean average of S/N ratio at the selected level. Table 5 lists the ANOM results and the fig 4 shows mean S/N graph. The different values of S/N ratio between maximum and minimum (main effect) are also shown in table 5. The feed rate is the factor with highest different in value i.e. **4.792**. Based on the Taguchi prediction that bigger different in value of S/N ratio shows more effect or more significant. Therefore, it can be concluded that feed rate has more effect on surface roughness. Main effect plot for S/N ratios on surface roughness is shown in Fig 3. From table 5 and Fig 3, the combination of machining parameters $A_1B_1C_1$ is found to be optimum for surface roughness during radius milling machine. It is found spindle speed of rpm, feed of mm/min and depth of cutoff mm resulted in minimum surface roughness of machined EN31 steel.

TABLE 5: ANALYSIS OF MEAN (ANOM)

S. No.	Symbol	Level 1	Level	Level 3	Max –Min
1	A	-8.502	-9.632	-9.243	1.130
2	B	-6.403	-9.779	-11.195	4.792
3	C	-8.325	-8.525	-10.527	2.202

From ANOM the best combination so generated is $\mathbf{A_1B_1C_1}$.

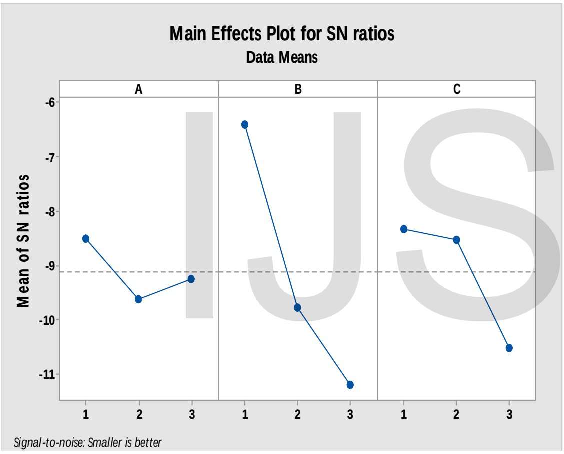

Fig 3. Mean S/N Graph

4.2 ANOVA

Normal probability plot (Fig. 4) was obtained to ensure that the data is normally distributed. It can be seen from Fig. 4 that the data points either lie on the straight line or are close to it which validates the normality assumption of the data. The purpose of ANOVA experiments is to reduce and control the variation of process, so the decisions can be made concerning which parameter affect the performance of the process. ANOVA is a statistical method used to interpret the experimental data to take necessary decisions. Through the ANOVA the parameters can be categorized into significant and insignificant parameters.

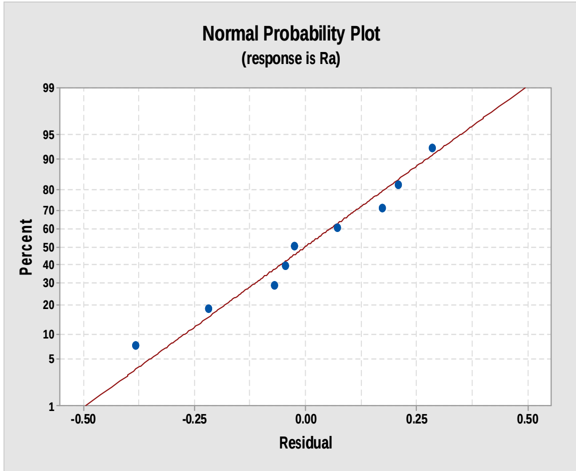

Fig 4. Normal probability plot

However Before applying ANOVA, normal probability plot (Fig. 4) was obtained to ensure that the data is normally distributed. It can be seen from Fig. 4 that the data points either lie on the straight line or are close to it which validates the normality assumption of the data. The importance of machining parameters was investigated to determine the optimum combinations of the machining parameters by using ANOVA. F-test provides a decision at some confidence level as to whether these estimates are significantly different.

TABLE 6. ANOVA RESULTS FOR SURFACE ROUGHNESS

Sources of variation	Sum of square	DOF	Mean square	F value	Percentage Contribution
Spindle speed (A)	1.976	2	0.9879	1.940	4.094
Feed rate (B)	36.363	2	18.1815	35.690	75.351
Depth of cut(C)	8.900	2	4.4501	8.740	18.442
Error	1.019	2	0.5094		2.111
Total	48.258	8			100

From F-value table and ANOVA table, it is found that **feed rate is the significant parameter for effecting surface roughness.** Also Fig.5, shows percentage contribution of feed rate (B) is maximum i.e.,**75.351%**followed by depth of cut(C) of 18.442% and spindle speed (A) of 4.094%. From the above result, it can be concluded that by selecting the suitable feed rate we can achieve the minimum surface roughness.

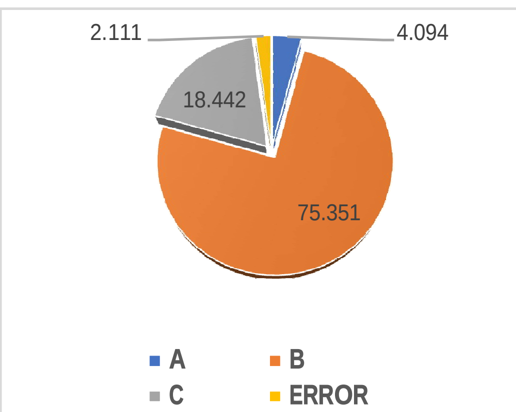

Fig 5. Contribution of Factors.

5 CONCLUSIONS

The effects of spindle speed, feed rate and depth of cut are experimentally investigated in machining of EN 31 steel using radius milling process. The Taguchi method was used to optimize the radius milling process parameters. Based on the results of the present study, the following conclusions are drawn:

1). Taguchi's robust design was successfully used for optimizing radius milling process parameters.

2). From the ANOM table the combination of machining parameters**$A_1B_1C_1$**is found to be optimum for the surface roughness. Therefore, it is recommended levels of the controllable parameters of the radius milling process for minimizing surface roughness.

3). Feed rate significantly affects the surface roughness whereas spindle speed and depth of cut were not significant for affecting the surface roughness

4). The order of importance for the controllable factors to the surface roughness average in sequence is Feed rate, depth of cut, spindle speed. Hence the Feed rate is the most dominating factor for radius milling process in the present study.

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