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Optimization Of End Milling Process Parameters On Surface Roughness Using Taguchi Method

Tasleem Ahmad*,Noor Zaman Khan*, Zahid A. Khan

Abstract—Present study investigated the optimization of CNC End milling process parameters using Taguchi method for minimizing the surface roughness (Ra) ofEN8 steel. Carbide end mill was used as a cutting tool for end milling operation on En8 steel. Taguchi method was used to optimize the end milling process parameters. Nine experiments were performed according to L_9 orthogonal array. Analysis of mean (ANOM) was used to obtain the optimum process parameter combination for minimizing the surface roughness. Analysis of variance (ANOVA) was performed to obtain the significance of the process parameters on the surface roughness of EN8 steel. The result of the present study reveals that the cutting speed at 4000 rpm, feed rate at 1000 mm/min and depth of cut at 0.10mm yields optimum value of performance characteristics i.e., minimum surface roughness. From the ANOVA results it is found that cutting speed significantly affect the surface roughness. Percentage contribution of the cutting speed was found to be maximum (90.24) followed by feed rate (4.30) and depth of cut (3.37). Hence the cutting speed is most dominant controlled factor for effecting surface roughness during end milling operation.

***Keywords*:**Taguchi method; ANOVA; CNC End milling EN8 steel; Cutting speed; Feed rate; Depth of cut.

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1 INTRODUCTION

EN8 is also known as 080M40 Unalloyed medium carbon steel. EN8 is a medium strength steel, good tensile strength. Suitable for shafts, stressed pins, studs, keys etc. AISI 1040. Available as normalized or rolled. EN8 is supplied as round drawn/turned, round hot rolled, hexagon, square, flats and plate.

EN8 is usually supplied untreated but can be supplied to order in the normalized or finally heat treated (quenched and tempered to "Q" or "R" properties for limiting ruling sections up to 63mm), which is adequate for a wide range of applications. Please refer to our selection guide for comparisons. EN8 is a very popular grade of through-hardening medium carbon steel, which is readily machinable in any condition. EN8 is suitable for the manufacture of parts such as general-purpose axles and shafts, gears, bolts and studs. It can be further surface-hardened typically to 50-55 HRC by induction processes, producing components with enhanced wear resistance. For such applications the use of EN8D (080A42) is advisable. It is also available in a free-machining version, EN8M(212A42).

EN8 in its heat treated forms possesses good homogenous metallurgical structures, giving consistent machining properties. Good heat treatment results on sections larger than 63mm may still be achievable, but it should be noted that a fall-off in mechanical properties would be apparent approaching the center of the bar. It is therefore recommended that larger sizes of EN8 are supplied in the untreated condition, and that any heat treatment is carried out after initial stock removal. This should achieve better mechanical properties towards the core. In past years, there are performed various statistical and experimental studies which are based on Taguchi L9 method to determine the effects of cutting parameters such as speed, feed and depth of cut on the surface roughness occurred in hard/finish milling of various materials by different type of CNC cutting tools.

2. Literature Review

Dave et al.(2012) studied on different materials like EN-8 and EN-31 in CNC turning process using TiN coated cutting tools. They selected inserts, work materials, speed, feed and DOC as machining parameters and Taguchi L8 orthogonal array. ANOVA has shown that the depth of cut has significant role to play in producing higher MRR and insert has significant role to play for producing lower surface roughness.Krishnakant et al. (2012) analyzed that an optimization of turning process by the effects of machining parameters applying Taguchi methods to improve the quality of manufactured goods, and engineering development of designs for studying variation. EN8 steel issued as the work piece material for carrying out the experimentation to optimize the Material Removal Rate. Kumar.Net al. (2014) described the effect of process parameters in turning of Carbon Alloy Steels in a CNC lathe. The parameters namely the spindle speed and feed rate are varied to study their effect on surface roughness. The experiments are conducted using one factor at a time approach. The five different carbon alloy steels used for turning are SAE8620, EN8, EN19, EN24 and EN47. The study reveals that the surface roughness is directly influenced by the spindle speed and feed rate. It is observed that the surface roughness increases with increased feed rate and is higher at lower speeds and vice versa for all feed rates. Magdum et al.(2013)this study used for optimization and evaluation of machining parameters for turning on EN8 steel on Lathe machine. This study investigates the use of tool materials and process parameters for machining forces for selected parameter range and estimation of optimum performance characteristics. Develop a methodology for optimization of cutting forces and machining parameters. Marimuthu et al.

(2013)were conducted experiments on EN8 material using End milling CNC machine based on Orthogonal array which provides a systematic and effective methodology for the design optimization of cutting parameters. The percentage contributions of parameters in affecting variation in surface roughness while machining EN8 steel with TNMG 160404 EN-TF CTC 2135 insert are: The feed has greater influence on the surface roughness followed by the cutting speed. From the analysis it is revealed that the feed, cutting speed and depth of cut are prominent factors which affect the facing operations. Confirmation test results proved that the determined optimal combination of machining parameters satisfy the real requirements of machining operations in the facing of EN8 materials.Nagaanjeneyulu et al. (2003)were conducted experiments on EN8 material using End milling CNC machine based on Orthogonal array . In his experiments, Experimental results demonstrate that the cutting speed and depth of cut are the main parameters that Influence the tool life of end mill cutters of CNC milling machine. The tool life can be improved simultaneous through Taguchi method approach instead of using Engineering judgment. The confirmation experiments were conducted to verify optimal cutting parameters.

This paragraph show literature review of cutting tool of different material, discussed the effect of tool and its geometry on work piece machining surface and tool life.

Arif et al. (2010**)** developed an analytical model based on Griffith's energy-balance criterion for brittle fracture to predict the critical chip thickness for ductile–brittle transition in micro-cutting of tungsten carbide by end-milling and established that ductile-mode machining of tungsten carbide can be performed efficiently by end-milling process within certain critical limits of cutting conditions governed mainly by the material properties and tool geometry.

Ghani et al. (2004) applied the Taguchi optimization method to optimize cutting parameters in end milling when machining hardened steel AISI H13 with TiN Coated P10 carbide insert tool under semi-finishing and finishing conditions of high-speed cutting. The milling parameters evaluated were cutting speed, feed rate and depth of cut. An orthogonal array, signal-to-noise ratio and Pareto analysis of variance were employed to analyze the effect of these milling parameters. The analysis of the result showed that the optimal combination for low resultant cutting force and good surface finish were high cutting speed, low feed rate and low depth of cut.Siddiquee et al. (2014**)** focused on optimizing deep drilling parameters based on Taguchi method for minimizing surface roughness by conducting experiments on CNC lathe machine using solid carbide cutting tool on material AISI 321 austenitic stainless steel and determined the machining parameter which significantly affects the surface roughness and also the percentage contribution of individual parameters. In this paragraph we will focused on systematic and efficient methodology for the design optimization of feed rate , depth of cut , and cutting parameters for improving the End milling operation and various factor. Avinash et al. (2015) have discussed an Optimization of Cutting Tool Life Parameters by Application of Taguchi Method on A CNC Milling Machine. In which the Experimental results demonstrate that the cutting speed and depth of cut are the main parameters that Influence the tool life of end mill cutters of CNC milling machine. The tool life can be improved simultaneous through Taguchi method approach instead of using Engineering judgment. The confirmation experiments were conducted to verify optimal cutting parameters. Chen and Li(1999)used orthogonal array of Taguchi method to minimize the surface roughness prediction technique for CNC end milling machine in which the system proved capable of predicting the surface roughness (Ra) with about 90%accuracy.Zhang*et al.* (2006) used Taguchi design of optimization to predict surface roughness CNC milling operation. An orthogonal array of L9(34)was used; ANOVA analyses were carried out to identify the significant factors affecting surface roughness, and the optimal cutting combination was determined by seeking the best surface roughness (response) and signal-to noise ratio. Finally, confirmation tests verified that the Taguchi design was successful in optimizing milling parameters for surface roughness.

Present paper investigated the effect of end milling machining parameters on the surface roughness of EN 8 steel according to Taguchi's L9 orthogonal array. Carbide (K10) end milling cutting tool was used for machining operations. The Taguchi L_9 (3^3) design is utilized for experimental planning for this purpose.

3. EXPERIMENTAL PROCEDURES AND TEST RESULTS

3.1. Materials

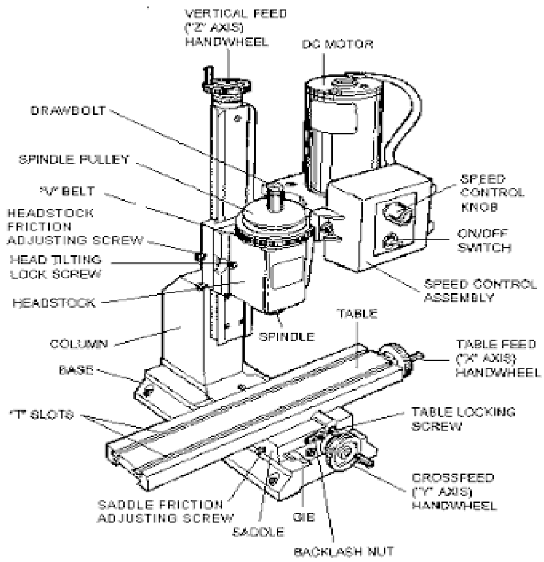
EN 8 steel with 100×100×20mm size was used as work-piece material. The composition of the work-piece material is shown in Table 1.

Table1: Material composition of EN 8 steel

Element	Concentration (% by weight)
Carbon	0.35-0.45
Silicon	0.15-0.35
Manganese	0.60-1.00
Sulphur	0.60
Phosphorous	0.60

3.2 Schematic of machining

The experimental studies were performed on CNC vertical milling machine**.**CNC stands for computer numerical control which refers to a computer controller that controls the movement of every axis of the machine using G and m codes instructions and drives the spindle or machine tool into a raw material to machine or to remove the unwanted material from work piece more accurately without human intervention. CNC vertical milling machine has three to five axes and it is used for wood, metal and plastic.



3.3. Measuring apparatus

The surface roughness values were measured by the surface roughness tester (model: SURFTEST, SV-2100; make: Mitutoyo, Japan).

3.4 Experimental parameters and 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 within the optimal level of process parameters. 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 using orthogonal 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 .In Taguchi method, a loss function is used to calculate the deviation between the experimental value and the desired value. This loss function is further transformed into a signal-to-noise (S/N) ratio. In end milling, the surface roughness should be minimum. Therefore, 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. It is denoted by 'η' with a unit of dB..

Table 2: Experimental factors and their levels

Factor	Level of Experimental factor		
	Level-1	Level-2	Level-3
A-cutting speed(rev/min)	2000	3000	4000
B-Feed rate (mm/min)	1000	1250	1500
C-Depth of Cut(mm)	0.05	0.10	0.15

Table 3: Orthogonal array L_9 (3^3) of the experimental runs

Expt. No.	A	B	C
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

were conducted with three controllable 3-level factors and one response variable. Nine experimental runs based on the orthogonal array L_9 (3^3) were carried out. Table 2 shows three controlled factors, i.e. at spindle speed (*A*) at 4000 rpm, feed rate (*B*) at 1000 mm/min, and depth of cut (*C*) at 0.10 mm, with three levels for each factor. Table 3 shows the nine cutting experimental runs according to the selected orthogonal table. After cutting, the values of surface roughness (i.e., R_a (μm)) were measured.

3. Results and discussion

The following sections describe the results of the present study and also present a discussion on the results in light of the available literature.

4 EXPERIMENTAL RESULTS

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

Table 4: Orthogonal array L_9 (3^3) of the experimental runs and results

Exp. No.	A	B	C	Ra(μm)	S/N ratio
1	2000	1000	0.05	3.40	-10.62
2	2000	1250	0.10	3.43	-10.70
3	2000	1500	0.15	3.53	-10.95

4	3000	1000	0.15	2.801	-8.94
5	3000	1250	0.05	3.265	-10.27
6	3000	1500	0.10	3.151	-9.96
7	4000	1000	0.10	0.458	6.78
8	4000	1250	0.15	0.747	2.53
9	4000	1500	0.05	1.196	-1.55

4.1 Analysis of means (ANOM)

In the analysis of means, mean value of the S/N ratio at each level of the process parameter is computed by taking arithmetic average of S/N ratio at the selected level. For example, the mean value of S/N ratio at level-1 of factor A is obtained by calculating average S/N ratio of run no.1, 2, and 3. In the same way mean value of S/N ratio at different levels of the factor is computed. it can be seen that the optimal combination of the machining parameters for surface roughness is $A_3B_1C_2$.Table 5 lists the ANOM results and Fig. 2 shows the mean S/N graph.

Table 5: Mean S/N ratio Table

Level	A	B	C
1	-10.76	-4.26	-7.48
2	-9.73	-6.15	-4.63
3	2.58	-7.49	-5.78

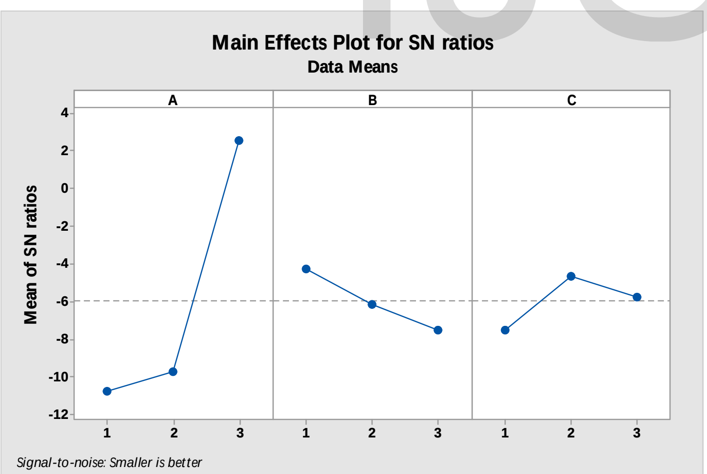


Fig. 2: Mean S/N graph

4.2 Analysis of Variance (ANOVA)

The analysis of variance (ANOVA) was conducted to study the significance of machining parameters on surface roughness based on their P-value and F-value at 5% level of significance. The ANOVA results are shown in Table 4.3. It can be seen from Table 4.3 that the spindle speed significantly affects the surface roughness as F calculated value is more than the tabulated F value ($F_{0.05}$, (2,2) = 19.00) whereas, feed rate and depth of cut do not have significant effect on surface roughness. However, based on the percentage contribution of the machining parameters shown in Table 4.3, it is found that % contribution of spindle speed is maximum (90.24%) followed by feed rate (4.30%) and depth of cut (3.37%). Results reveal that spindle speed is the dominant machining parameter effecting the surface roughness of machined EN 8 alloy steel.

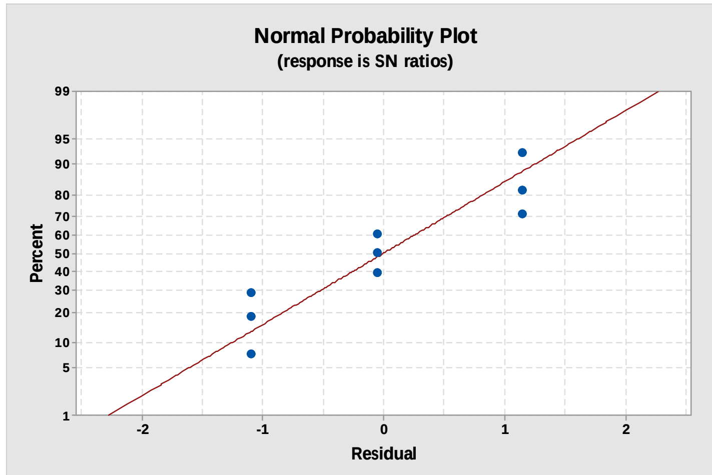


Fig. 3: Normal probability plot.

Table 6: ANOVA results for Surface roughness

Factor	Degreeof freedom	Sum of squares	Mean square	F value	Contribution (%)
A	2	331.050	165.525	43.44	90.24
B	2	15.783	7.892	2.07	4.30
C	2	12.385	6.193	1.63	3.37
Error	2	7.620	3.810		2.07
Total	8	366.839			100.00

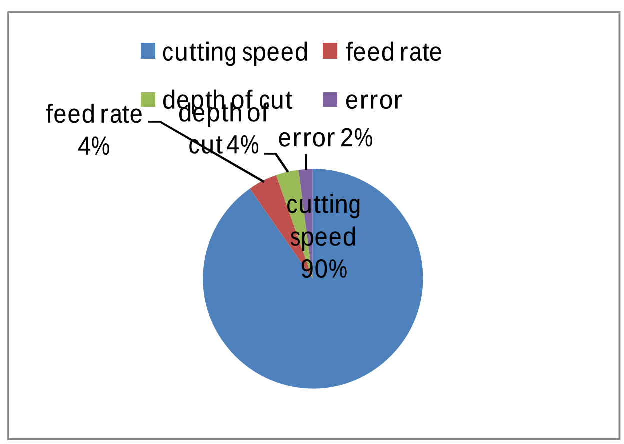


Fig. 4: Pie-chart of Contribution factors of cutting parameters.

5. Conclusion

Present paper investigated the effect of end milling machining parameters on the surface roughness of EN 8 steel according to Taguchi's L9 orthogonal array. Carbide (K10) end milling cutting tool was used for machining operations. Taguchi method provides a systematic and efficient methodology for the design optimization of the cutting parameters with far less effect than would be required for most optimization techniques. It has been shown that surface roughness can be improved significantly for End milling operations using Taguchi method. Based on experimental results, following conclusions are made:

- It is found that the largest value of **cutting speed of 4000m/min, the feed rate of 1000 mm/rev, and depth of cut of 0.10mm.** It is recommended levels of the controllable parameters of the milling operations as minimization of the roughness.

- Through ANOVA, the percentage of contribution to the end milling process, in sequence the **cutting speed (90.24%), the feed rate (4.30%) and depth of cut (3.36%).** Hence the cutting speed is most significant controlled factor for the end milling operation when minimization of the roughness average.
- Experimental results have shown clearly that the surface roughness in end milling operation can be improved effectively through the proposed approach. As a result, optimization of the complicated performance characteristics of the end milling process such as surface roughness improved by using the method proposed by this study.
- Increase in the spindle speed leads to the decrease in the surface roughness and vice versa.
- Increase in the feed rate leads to the increase in the surface roughness as shown in the S/N graph.
- The combination of machining parameters $A_3B_1C_2$ is found to be optimum for surface roughness i.e., **spindle speed at 4000 rpm, feed rate at 1000 mm/min and depth of cut at 0.10.**
- The order of the importance for the controllable factors to the surface roughness average, in sequence, is the spindle speed, feed rate and depth of cut.Hence, the spindle speed is the most significant controlled factor for the end milling operation in the present study.

This paper also demonstrates the effectiveness of the Taguchi approach to optimize machining parameters with minimum number of experiments.

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