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Optimization of Turning Process Parameters for Surface Roughness of EN-31 Steel using Taguchi Robust Method.

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Abstract - In the modern world, the quality of surface finish is most important requirement for any turned work-piece due to which manufacturers are seeking to remain competitive in market. Present paper presents a study that investigates the effect of turning three process parameters such as rotational speed, feed rate and depth of cut each at level three on surface roughness of EN-31 steel using Taguchi robust method. Surface roughness is selected as the quality target. The experimental plan is based on Taguchi's L9 Orthogonal array and was used for designing the experiments and optimization of turning process parameters. Nine experiments were conducted as per L9 (O.A). The experiments were conducted on CNC-lathe machine using carbide cutting tool. The analysis of variance (ANOVA) technique is employed to study the significance and contribution percentage of each factor on surface roughness. Results revealed that factor (B) i.e., feed-rate has a significant effect on surface roughness in turning process and it is the most dominating factor affecting the surface roughness with contribution of 87.49 %. The optimal turning process parameter combination for minimum surface roughness is found to be $A_1B_1C_1$ i.e., Spindle Speed (A) of 350 rpm, Feed Rate (B) of 60 mm/min and Depth of Cut (C) of 0.4 mm.

Key words – Optimization, Taguchi method, L9 Orthogonal array, EN-31 steel, ANOVA.

I. INTRODUCTION

Machining is a versatile shaping process of major importance for component manufacturing. The importance of machining in modern automated manufacturing systems has in fact increased due to the significant increase in the production time and the need to offset the high capital investment in these modern systems. Turning is a very basic operation and generally produces cylindrical surfaces[1]. The machine tool used for this type of operation is known as CNC-lathe. Turning is one of the most commonly employed operations in experimental work and metal cutting. The tool is held rigidly in a tool post and moved at a constant rate along the axis of the bar, cutting away a layer metal to form a surface or more complex profile as the part is being rotated. Turning is also used to as a secondary process to produce better surface finish after being processed by primary processes such as casting, forging, extrusion or drawing process[2]. Turning generates axially symmetric shapes with a single-point tool. A single-point tool removes material by means of one cutting edge. In most cases the tool is held in a fixed position with the work piece rotating about a turning axis. There are also, tools held on the spindle centreline (drills, reamers, taps) for hole-making applications that have speed and feed limitations. Turning is a manufacturing process which carried out through relative rotation of part and cutting tool. The main power comes from the work piece which mounted in the chuck derived by the motor. Turning is the most basic and common machining method which plays an important role in production in many shops. Turning is suitable for processing rotary surface, most of the work piece with the rotary surface can be processed with the turning method, such as internal and external cylindrical surface, inside and outside the cone surface, face, groove, thread and rotating forming surface etc [3]. In various metal cutting machine tools, the lathe is the most common kind, accounting for 50% of the total number of machine tools. Lathe tool can be used for turning on the work piece, and also drill bits, reamers, taps and knurl for drilling, reaming, tapping and knurling operation. Turgay and Kıvak [3]optimized surface roughness and flank wear using taguchi's method in milling process with PVD and CVD coated inserts, they found its feed rate which has dominant effect on surface roughness, whereas cutting speed was the dominant factor affecting flank wear Mir et al. [4] investigated the effect of milling process parameters on surface roughness of EN 31 steel, and they found A1B1C1 as optimal combination, whereas, the feed rate which significantly affected the response with 75.351 % contribution. Verma and Sikarwar [5] optimized turning process by using taguchi's method and found feed rate as most significant factor with 47.51 % contribution. Sonowal et al.[6] used taguchi's method to optimize cutting parameters in turning AISI 1020 MS with M2 HSS tool and they found feed has the maximum effect on both mean and variation of the response with 50.650 % and 62.727% respectively. Das et al.[7] investigated optimization of cutting parameters on tool wear, workpiece surface temperature and material removal rate during turning of AISI D2 steel.

II. DESIGN METHODOLOGY AND MATERIAL USED

2.1. Material and Machine

EN-31 steel is used as a base material in present investigation. This steel is direct hardening materials and can be hardened to 58-60 HRC. This steel has good hardness which leads to its use for manufacturing press tools and sheering blades. EN-31 steel is highly used in manufacturing industries[4]. This steel has good hot hardness and strength. Common applications for these tool steels include forging dies, die-casting die blocks, and drawing dies. The chemical composition of HC steel is presented in Table 1. Also, the experimental studies were performed on a CNC-lathe machine as shown in Fig. 1 below.

Table 1: Chemical Material Composition of EN-31 Steel

Element	**Composition (Wt %)**
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

Fig. 1. CNC-Lathe machine

2.2. Experimental Design

Taguchi method, a powerful tool for parameter design of performance characteristics, was used to determine optimal machining parameters for minimum surface roughness in turning process[1], [2], [8]. 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. 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. Also, a statistical analysis of variance (ANOVA) is performed to identify the process parameters that are statistically significant[9]. The lower the better criterion for the surface roughness was selected for obtaining optimum machining performance characteristics.

For lower the better criteria, S/N ratio values corresponding to the experimental values of surface roughness was calculated using the below Eq. 1.

$$S/N = -10\log\left[1/n \sum_{i=1}^{n} {y_i}^2\right] \quad (1)$$

Where yi is observed Ra at ith experimental trial, n represents the total experimental trials.

2.3. Design of Experiments (DOE) and Process Parameters

The DOE help for conducting experiments in a more systematic way[10]. The process parameters with their levels are specified in Table 2 below. Table 2 shows three parameters, i.e., spindle speed (A), feed rate (B), and depth of cut (C), with three levels for each factor.

Table 2: Experimental Factors and their Levels

Factor	Symbol	Level-1	Level-2	Level-3
Spindle speed	A	350	450	550
Feed rate	B	60	80	100
Depth of cut	C	0.4	0.6	0.8

2.4. Orthogonal Array (OA)

Nine experimental runs based on the orthogonal array L9 were carried out. OA allows for the maximum number of main effects to be estimated in an orthogonal manner, with minimum number of runs in experiment[11]. L9 orthogonal array used in the study as presented in Table 3.

Table 3: L9 orthogonal array

Exp. 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

III. RESULTS AND DISCUSSIONS

Nine experiments were successfully conducted based on Taguchi method and machined samples are shown in Fig. 2. 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[12]. Thus, the data sequences have a “smaller- the-better characteristic" for surface roughness.

Table 4: Experimental results and S/N ratio

Exp. No	A	B	C	Ra(µm)	S/N Ratio
1	350	60	0.4	0.574	1.16
2	350	80	0.6	2.880	-9.18
3	350	100	0.8	4.103	-12.26
4	450	60	0.8	1.201	-1.59
5	450	80	0.4	2.978	-9.47
6	450	100	0.6	3.892	-11.80
7	550	60	0.6	0.635	3.94
8	550	80	0.8	3.965	-11.96
9	550	100	0.4	4.254	-12.57

Fig 2. Machined workpieces

3.1 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. 3 shows mean S/N graph. The combination of machining parameters A1B1C1 is found to be optimum for surface roughness during turning of high carbon steel. Spindle speed at 315 rpm, feet rate of 15 mm/min and depth of cut of 0.8 mm is found to be optimum parameter combination for minimizing surface roughness of high carbon steel. Hence, Taguchi method optimizes the parameters not only those available in the selected design but it optimizes from all possible combinations[13]. Also, the histogram plot is shown in Fig. 3

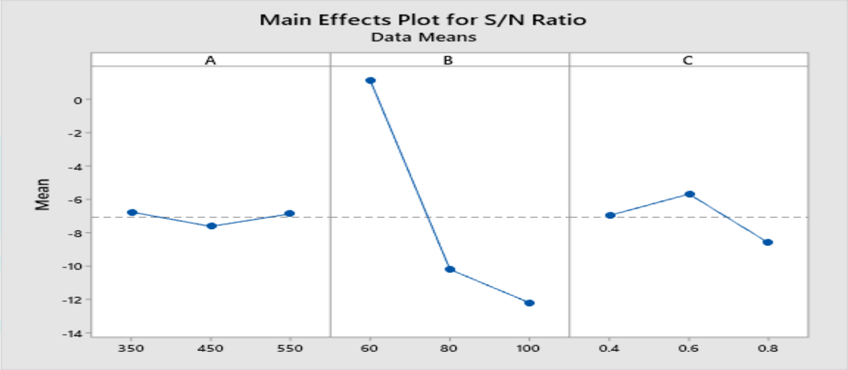

Fig. 3. Mean S/N Graph

Table 5: Analysis of Mean (ANOM)

S. No	Symbol	Level-1	Level-2	Level-3
1	A	-6.76	-7.62	-6.86
2	B	1.17	-10.20	-12.11
3	C	-4.96	-5.68	-8.60

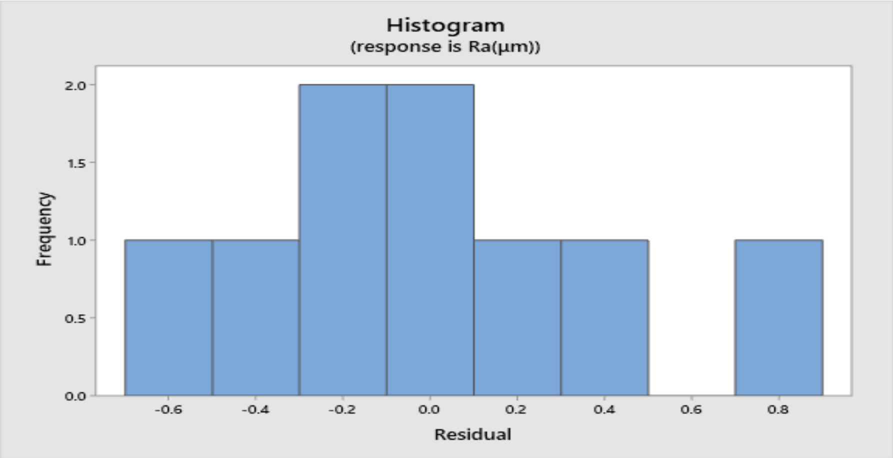

Figure 4. Histogram plot

3.2 ANOVA

Table 6: ANOVA results for surface roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
A	1	0.165	0.165	0.47	0.525
B	1	15.165	15.165	42.66	0.001
C	1	0.225	0.225	0.63	0.462
Error	5	1.777	0.355		
Total	8	17.333			

Normal probability plot (Fig. 5) was obtained to ensure that the data is normally distributed. It can be seen from Fig. 5 that the data points either lie on the straight line or are close to it which validates the normality distribution of the measured 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[14]. ANOVA is a statistical method used to interpret the experimental data to take necessary decisions. Through ANOVA the parameters can be categorized into significant and insignificant parameters.

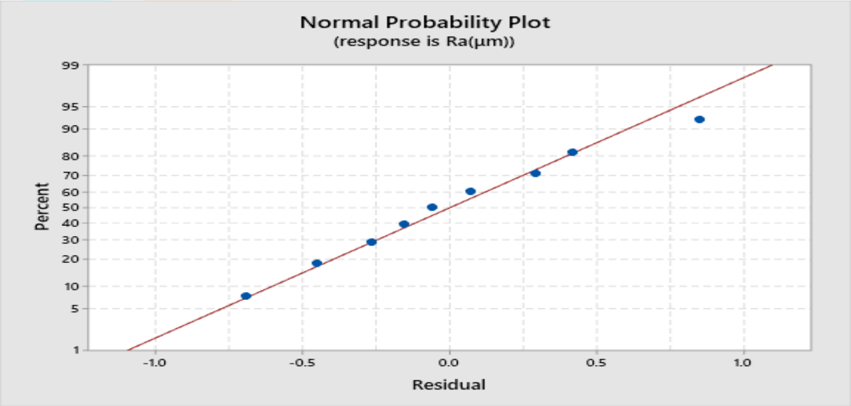

Fig. 5. Normal probability plot

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. From F-value table and ANOVA table, it is found that feed rate is the significant parameter for effecting surface roughness. Also Fig.6 shows percentage contribution of feed rate (B) is maximum i.e., 87.49%, while as spindle speed (A) of 0.95%, depth of cut(C) of 1.29% and error at 2.04 %.

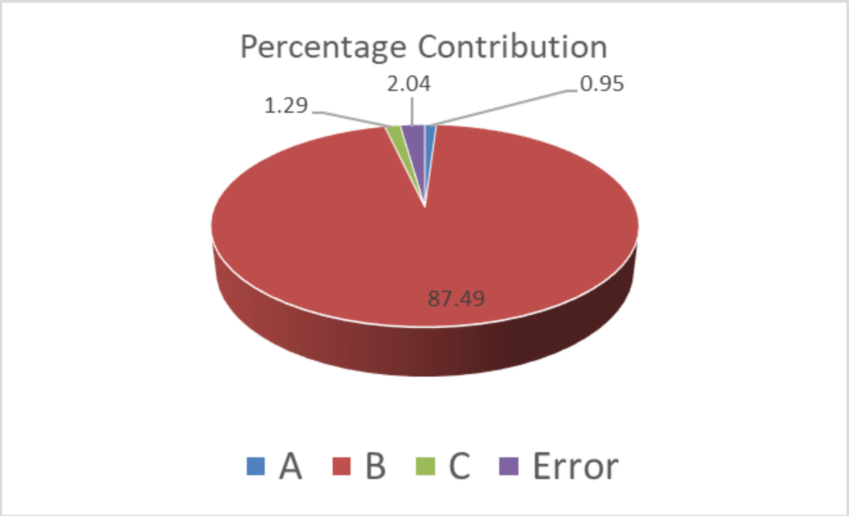

Fig 6. Percentage contribution

IV. CONCLUSIONS

In this paper, effect of turning parameters on surface roughness of high carbon steel using carbide tool was investigated. Experimentation was done as per Taguchi's L9 orthogonal array. Optimal combination of machining parameters and their levels for minimum surface roughness was obtained and significance of the machining parameters was determined using ANOVA. Based on the results of the present study following conclusions are drawn:

1). Taguchi's robust design was successfully used for optimizing turning parameters on EN-31 steel.

2). Optimal combination of the machining parameters for surface roughness is found to be $A_1B_1C_1$, i.e., at spindle speed (A) at 350 rpm, feed rate (B) at 60 mm/min, and depth of cut (C) at 0.4 mm. Surface roughness value obtained at optimum parameter combination was 0.891µm.

3). Feed rate contributes maximum (87.49%) followed by spindle speed (0.95%) and depth of cut (1.29%) to minimize the surface roughness.

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