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International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429 Volume 5, Issue 8, May 2025 Impact Factor: 7.67

Experimental Evaluation and Optimization of Machining Parameters of EN31 Alloy Steel in Cylindrical Grinding

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Abstract: *The current study focuses on analysing how certain process parameters affect performance outputs. The parameters examined include feed rate (mm/min), workpiece speed (rpm), and depth of cut (mm), while the key response variables are surface roughness (Ra) and material removal rate (MRR). The experiments utilize EN31, a high-strength alloy steel commonly used in the manufacture of components such as crankshafts, gear shafts, and connecting rods in the aerospace and heavy vehicle sectors. To determine the optimal combination of process settings, the Taguchi Design of Experiments (DOE) method with an L16 orthogonal array was employed, followed by optimization using Grey Relational Analysis (GRA). The optimal results obtained were: surface roughness (Ra) of 0.615 µm and MRR of 1.13984 grams/second, achieved at a work speed of 620 rpm, feed rate of 32.4 mm/min, and depth of cut of 0.04 mm.*

Keywords: Cylindrical grinding, Workpiece speed, Feed rate, Depth of cut, Material removal rate (MRR), Surface roughness (Ra), Taguchi method, Grey relational analysis (GRA).

I. INTRODUCTION

In this experimental study, EN31 alloy steel has been selected as the workpiece material to achieve minimal surface roughness and maximum metal removal rate during cylindrical grinding

EN31 is a high carbon chromium alloy steel known for its high degree of hardness and wear resistance. It is commonly available in various forms such as round bars, flat bars, square bars, and plates [3]. EN31 is primarily used in manufacturing components that require high strength and resistance to wear, such as bearings, shafts, spindles, gears, and dies. Due to its hardness and ability to retain shape under stress, it is ideal for high-load applications [4,5].

Taguchi method is widely employed technique for optimization of machining parameters and by adopting grey relational analysis (GRA), the optimization of multi-response parameters is possible [6,7]. This technique gives better results based on experimental data for solving the complex system.

II. MATERIALS AND METHODOLOGY

In this experimental study, EN31 alloy steel has been selected as the workpiece material to achieve minimal surface roughness and maximum metal removal rate during cylindrical grinding. The dimensions of the workpiece used are 31 mm in diameter and 120 mm in length. Typically supplied in the 'T' condition, EN31 steel has a tensile strength ranging between 850 and 1000 N/mm². and toughness

Table 1Chemical Composition of EN31 Steel

Chemical Composition	Percentage(%)
Carbon C %	0.929
Silicon Si%	0.214
Manganese Mn%	0.352
Phosphorus P%	0.034

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Chromium Cr %	1.3
Sulphur S %	0.012

To optimize manufacturing processes, several techniques are utilized. These methods are aimed at improving both the process efficiency and the quality of the final product. In this particular experimental work, four levels of design with three control factors were utilized [7].In the current research, the L16 orthogonal array has been utilized. This array is particularly useful when dealing with several factors at multiple levels, offering a practical balance between the number of trials and the quality of results. The properties and structure of the L16 array are outlined below:

No. of experiments = 16

No. of levels = 4(A, B, C, D)

No. of factors = 3(Workpiece Speed, Feed Rate, Depth of Cut).

Control factors are represented in Table 2.

Table 2 Levels of Control Factors

Control factor	Units	Levels			
		I	II	III	IV
Work piece speed	RPM	110	150	440	620
Feed rate	mm/min	15.6	32.4	45.8	65.4
Depth of cut	Mm	0.02	0.04	0.06	0.08

The specimens were then prepared for experimental testing. Each of the 16 samples was labelled sequentially from 1 to 16 to align with the experimental plan based on the L16 orthogonal array. The prepared and labelled specimens are shown in Figure 1.

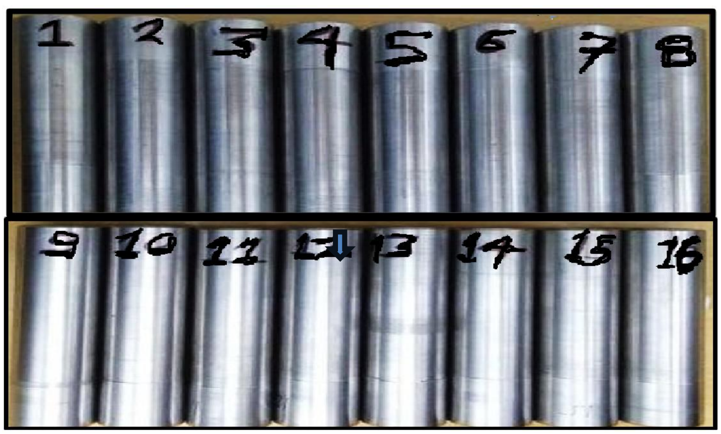

Figure 1 Specimen Numbering System

In addition to surface roughness, the material removal rate (MRR) was also determined [10]. The weight of each workpiece was recorded before and after the grinding operation using a precision weighing scale. These measurements were taken individually for all 16 samples. The duration of each grinding experiment was recorded using a stopwatch. MRR was then calculated by dividing the difference in workpiece weight (before and after grinding) by the corresponding machining time.In this study, the grey relational analysis (GRA) method is employed to optimize multiple response parameters. The primary objective is to achieve the lowest possible surface roughness while maximizing the material removal rate. To accomplish this, GRA is utilized as the optimization technique. The analysis follows a series of structured steps to process the data accordingly [8,9].

Design of Experiments Steps used:

The Taguchi method was employed to design the experiments using MINITAB 17 software. This approach provides a structured and efficient way to study the effect of multiple control factors on machining performance. The following steps outline the procedure used for designing the experiments:

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Step 1: A Taguchi design was generated using MINITAB 17.

Step 2: Three key control parameters- workpiece speed (v), feed rate (f), and depth of cut (d) were selected. Each parameter was assigned four levels to gain a deeper understanding of their influence on the cylindrical grinding process.

Step 3: Based on the number of factors and their levels, the L16 orthogonal array was chosen, as it provides an optimal and balanced design for this type of experiment within MINITAB.

Step 4: The selected values for each control factor were input into the software and assigned to their respective levels.

Step 5: Finally, MINITAB generated 16 experimental runs, each representing a unique combination of the control parameters, as required by the L16 orthogonal array.

III. RESULTS AND DISCUSSION

In alignment with the Taguchi design methodology, all experiments on the cylindrical grinding machine were conducted successfully. The process was carried out under optimal conditions aimed at achieving the highest quality results. For each of the 16 specimens, both surface roughness and material removal rate were measured to evaluate performance. The response values for these parameters are summarized in Table 3.

No. of Exp.	**Workpiece Speed (v) RPM**	**Feed Rate(f) mm/min**	**Depth of Cut(d) mm**	**Material Removal rate (MRR) gm/sec**	**Surfac eRoughness(Ra) µm**
1.	110	15.6	0.02	0.03220	0.23500
2.	110	32.4	0.04	0.17612	0.27300
3.	110	45.8	0.06	0.11432	0.32650
4.	110	65.4	0.08	0.47622	0.35700
5.	150	15.6	0.02	0.14125	0.24240
6.	150	32.4	0.04	0.28935	**0.22254**
7.	150	45.8	0.06	0.71982	0.51200
8.	150	65.4	0.08	0.39216	0.49800
9.	440	15.6	0.02	0.18356	0.25700
10.	440	32.4	0.04	0.31254	0.52740
11.	440	45.8	0.06	0.92564	0.42900
12.	440	65.4	0.08	0.64272	0.53900
13.	620	15.6	0.02	0.22453	0.35780
14.	620	32.4	0.04	1.13984	0.61500
15.	620	45.8	0.06	**1.44654**	0.69100
16.	620	65.4	0.08	1.24146	0.73940

Based on the experimental data collected, the highest Material Removal Rate (MRR) of 1.44654 grams per second was achieved at a workpiece speed of 620 rpm, a feed rate of 45.8 mm/min, and a depth of cut of 0.06 mm. Similarly, the lowest surface roughness (Ra) value of 0.22254 µm was obtained at a workpiece speed of 150 rpm, a feed rate of 32.4 mm/min, and a depth of cut of 0.04 mm.

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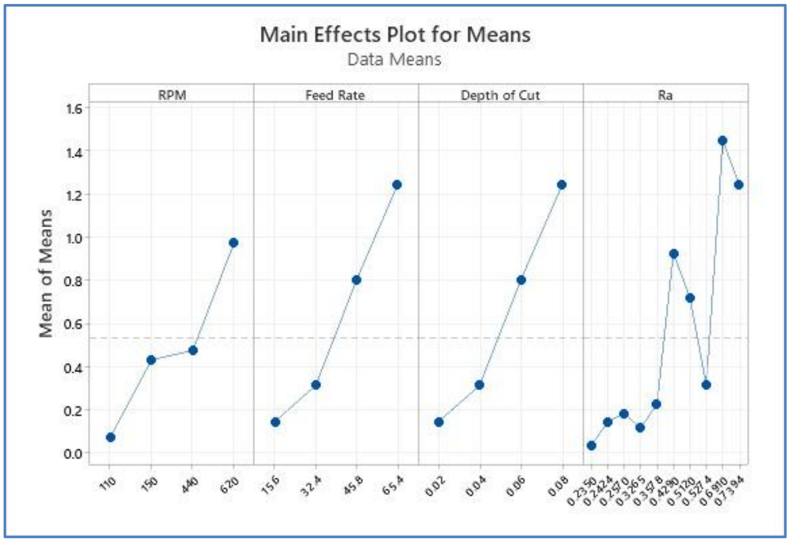

Figure 2 MRR versus Control parameters

As shown in Figure 2, the Material Removal Rate (MRR) increases as both the workpiece speed and the feed rate are elevated. In contrast, increasing the depth of cut leads to a reduction in MRR. To further evaluate the influence of each machining parameter, a Signal-to-Noise (S/N) ratio analysis was performed. The results revealed that workpiece speed had the most significant impact on MRR, exhibiting the highest delta value of 21.7105. This was followed closely by feed rate, with a delta of 20.5142. On the other hand, depth of cut contributed the least to changes in MRR, as indicated by the smallest delta of 1.09607.

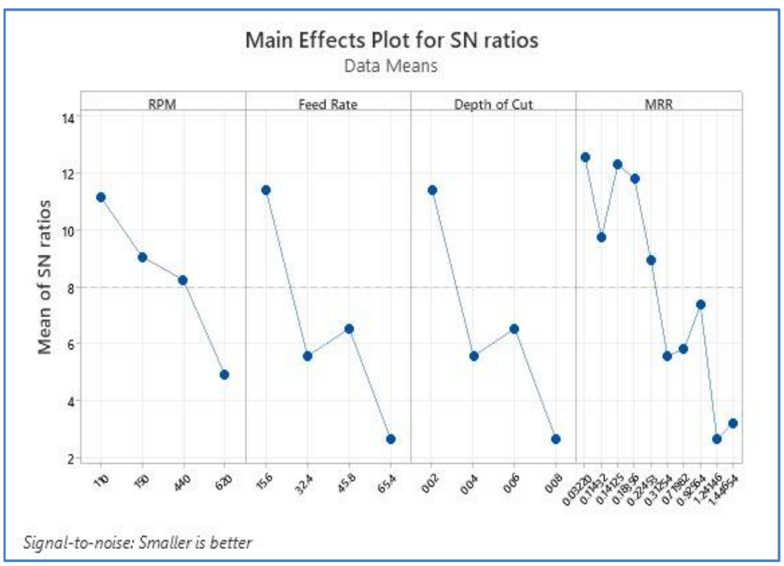

Figure 3 Ra versus control parameter

Based on their influence on the Material Removal Rate (MRR), workpiece speed ranks first, followed by table feed in second place, and depth of cut in third, as determined from the analysis. Similarly, when evaluating their effects on surface roughness (Ra), table feed has the most significant impact, exhibiting the highest delta value of 4.301, followed by workpiece speed with a delta of 4.124. The depth of cut again shows the least influence, with the lowest delta value of 1.217.

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IV. CONCLUSION

This experimental investigation focused on the cylindrical grinding of EN31 alloy steel, specifically targeting the optimization of material removal rate (MRR) and surface roughness (Ra) through Grey Relational Analysis (GRA). The following conclusions have been drawn:

The Taguchi Design of Experiments (DOE) approach using MINITAB 17 software, combined with GRA, proved effective for predicting and optimizing MRR and Ra in cylindrical grinding.

GRA successfully identified the best set of multi-response parameters for the process.

Among the input parameters, work speed, feed rate, and depth of cut were found to significantly influence both MRR and Ra.

The optimal results obtained were: surface roughness (Ra) of 0.615 µm and MRR of 1.13984 grams/second, achieved at a work speed of 620 rpm, feed rate of 32.4 mm/min, and depth of cut of 0.04 mm.

Work speed and feed rate were found to have a greater influence on surface roughness, while depth of cut had a relatively lower impact on MRR.

An increase in work speed led to improved (lower) Ra, whereas increasing the depth of cut resulted in a higher Ra..

ACKNOWLEDGMENT

The authors are highly grateful to universities in India for their support to provide the necessary equipment's and laboratories for conducting required tests and analysis for the study

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