Int. j. adv. multidisc. res. stud. 2026; 6(2):1553-1555

Received: 27-02-2026
Accepted: 07-04-2026

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

A Taguchi Approach for Evaluating Surface Roughness in Turning of C45 Steel

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Abstract
This study investigates the effects of machining parameters on surface roughness in turning of C45 steel under dry and minimum quantity lubrication (MQL) conditions. The experiments were designed using the Taguchi L8 orthogonal array with four factors, including cooling condition, cutting speed, feed rate, and depth of cut. Surface roughness (Ra) was used as the performance indicator. The results show that Ra values range from 1.12 µm to 1.95 µm. The minimum surface roughness was obtained under MQL with high cutting speed (180 m/min), low feed rate (0.1 mm/rev), and shallow depth of cut (0.5 mm). Signal-to-noise analysis indicates that cooling condition is the most significant factor, followed by feed rate and depth of cut. ANOVA results confirm that these factors significantly affect surface roughness, while cutting speed has a minor influence. The findings demonstrate that MQL improves surface quality and provides an effective approach for enhancing machining performance.

Keywords: C45 Steel, Taguchi Approach, Minimum Quantity Lubrication (MQL)

Introduction

C45 steel is a widely used medium carbon steel in mechanical engineering due to its good balance between strength, toughness, and machinability [1, 2]. It is commonly applied in the manufacturing of shafts, gears, and structural components subjected to moderate loading conditions. In industrial practice, turning is one of the most frequently used machining processes for shaping C45 steel. Therefore, improving machining performance, especially surface quality, is of great importance for enhancing the functional performance and service life of machined components.

Surface roughness is a critical indicator of product quality in machining processes, as it directly affects wear resistance, fatigue strength, and assembly accuracy [3, 4]. Among various factors influencing surface roughness, machining parameters such as cutting speed, feed rate, and depth of cut play a decisive role [5, 6]. In particular, feed rate is often considered the most influential factor due to its direct relationship with the geometric characteristics of the machined surface [7, 8]. Therefore, the proper selection and optimization of cutting parameters are essential to achieving improved surface finish in turning operations.

In addition to cutting parameters, cooling and lubrication conditions significantly affect machining performance. Conventional flood cooling has been widely used; however, it poses environmental and economic concerns [9, 10, 11]. As a result, dry machining and minimum quantity lubrication (MQL) have emerged as promising alternatives. Dry machining eliminates the use of cutting fluids, offering environmental benefits but often at the cost of increased friction and tool wear [10, 12, 13]. In contrast, MQL provides a small amount of lubricant directly to the cutting zone, reducing friction and improving surface quality while maintaining sustainability [14, 15, 16].

In this study, the effects of machining parameters and cooling conditions on surface roughness in turning of C45 steel are investigated using the Taguchi method. The main objective is to evaluate the influence of cutting parameters under dry and MQL conditions and to determine the optimal machining settings for minimizing surface roughness. The findings are expected to provide practical guidance for improving machining efficiency and surface quality in industrial applications.

Experiment setup

The experiments were carried out on an EMCO Maxxturn 45 CNC lathe under controlled laboratory conditions. The work piece material used in this study was C45 steel with a diameter of 40 mm and an average hardness of approximately 200 HB. Carbidecutting tools were employed for all turning operations to ensure stable cutting performance.

Table 1: Input machining parameters and their levels

Factor	Parameter	Unit	Low	High
A	Cooling condition	–	Dry	MQL
B	Cutting speed (V)	m/min	120	180
C	Feed rate (f)	mm/rev	0.1	0.2
D	Depth of cut (ap)	mm	0.5	1

The machining parameters and their levels were selected based on practical machining conditions and are presented in Table 1. Four input factors were considered, including cooling condition (dry and minimum quantity lubrication – MQL), cutting speed (120 and 180 m/min), feed rate (0.1 and 0.2 mm/rev), and depth of cut (0.5 and 1.0 mm). The experiments were designed using the Taguchi L8 orthogonal array.

Surface roughness (Ra) was measured using a Mitutoyo SJ-401 surface roughness tester. For each experimental run, measurements were taken at multiple locations along the machined surface, and the average value was recorded to ensure reliability.

In the MQL condition, canola oil (peanut oil) was used as the base lubricant and supplied directly to the cutting zone in a minimal quantity. Dry cutting was performed without the use of any coolant or lubricant for comparison purposes.

Results and Discussion

The experimental results of surface roughness (Ra) under different machining conditions are presented in Table 2. The obtained Ra values range from 1.12 µm to 1.95 µm, indicating that machining parameters and cooling conditions have a significant influence on surface quality. The minimum surface roughness (1.12 µm) was achieved under MQL condition at a cutting speed of 180 m/min, feed rate of 0.1 mm/rev, and depth of cut of 0.5 mm (Run 7). In contrast, the maximum Ra value (1.95 µm) was observed under dry machining with higher feed rate and depth of cut (Run 4). These results clearly indicate that MQL improves surface finish compared to dry cutting.

Table 2: Experimental layout and surface roughness results

Run	Cooling condition	Cutting speed V (m/min)	Feed rate f (mm/rev)	Depth of cut ap (mm)	Ra (µm)
1	Dry	120	0.1	0.5	1.45
2	Dry	120	0.1	1	1.62
3	Dry	180	0.2	0.5	1.78
4	Dry	180	0.2	1	1.95
5	MQL	120	0.2	0.5	1.42
6	MQL	120	0.2	1	1.55
7	MQL	180	0.1	0.5	1.12
8	MQL	180	0.1	1	1.25

The main effects plot for S/N ratios (smaller-is-better), as shown in Figure 1, illustrates the influence of each factor on surface roughness. It can be observed that the optimal levels for minimizing Ra are MQL cooling condition, high cutting speed (180 m/min), low feed rate (0.1 mm/rev), and low depth of cut (0.5 mm). Among all factors, the cooling condition exhibits the steepest slope, indicating that it is the most significant factor affecting surface roughness. Feed rate is the second most influential factor, while depth of cut shows a moderate effect. Cutting speed has the least influence within the selected range.

The significance of machining parameters was further evaluated using analysis of variance (ANOVA), as presented in Table 3. The results reveal that cooling condition, feed rate, and depth of cut significantly influence surface roughness ($P < 0.05$), whereas cutting speed has no statistically significant effect ($P > 0.05$). Among these factors, cooling condition and feed rate show dominant contributions, as indicated by their high F-values.

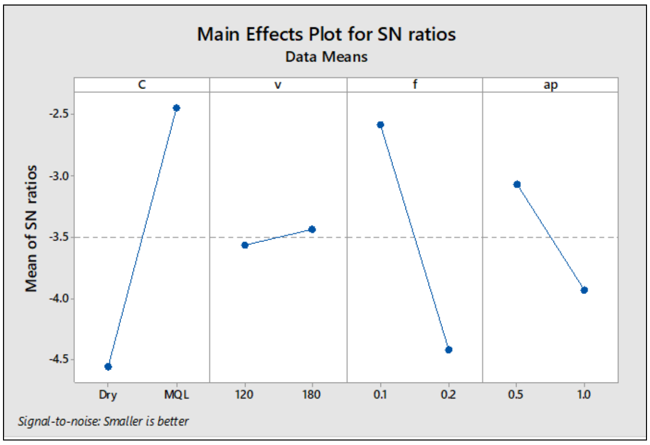

Fig 1: Main Effects Plot for SN ratio

From a physical perspective, the improvement in surface roughness under MQL can be attributed to better lubrication and cooling at the cutting interface, which reduces friction and tool-workpiece adhesion [17]. On the other hand, higher feed rate increases the feed marks on the machined surface, leading to higher roughness values [4, 18]. The relatively small effect of cutting speed may be due to the limited variation range used in this study.

Table 3: Analysis of Variance

Source	DF	Adj-SS	Adj-SS	F-Value	P-Value
C	1	0.266450	0.266450	999.19	0.000
v	1	0.000450	0.000450	1.69	0.285
f	1	0.198450	0.198450	744.19	0.000
ap	1	0.045000	0.045000	168.75	0.001
Error	3	0.000800	0.000267		
Total	7	0.511150			

Conclusion

This study investigated the effects of machining parameters and cooling conditions on surface roughness in turning of C45 steel using the Taguchi method. The experimental results showed that surface roughness is significantly influenced by cooling condition, feed rate, and depth of cut, while cutting speed has a negligible effect within the selected range. Among all factors, cooling condition was identified as the most significant parameter based on signal-to-noise analysis.

The application of MQL significantly improved surface quality compared to dry machining, with the lowest Ra value of 1.12 µm achieved at a cutting speed of 180 m/min, feed rate of 0.1 mm/rev, and depth of cut of 0.5 mm. The findings highlight the effectiveness of MQL in reducing friction and enhancing machining performance.

Overall, this study provides a simple and practical approach for optimizing machining parameters to achieve better surface finish in turning operations.

Acknowledgment

This research was conducted with the support of Thai Nguyen University of Technology.

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