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Effect of Cutting Parameters on Cutting Temperature in C45 Steel Turning under Canola Oil-Based MQL

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Abstract

Cutting temperature is one of the most critical factors affecting machining performance, tool life, and surface quality in turning operations. This study investigates the influence of cutting parameters on cutting temperature during the turning of C45 steel under canola oil-based minimum quantity lubrication (MQL) conditions. A Taguchi L9 orthogonal array was employed to evaluate the effects of cutting speed, feed rate, and depth of cut. Analysis of signal-to-noise (S/N) ratios and analysis of variance (ANOVA) were used to determine the significance of each machining parameter and identify the optimal cutting conditions. The results revealed that cutting speed was the most influential factor, contributing approximately 76% to the variation in cutting temperature, followed by feed rate and depth of cut. The optimal parameter combination for minimizing cutting temperature was found to be a cutting speed of 120 m/min, a feed rate of 0.05 mm/rev, and a depth of cut of 0.5 mm. The findings demonstrate that canola oil-based MQL is an effective and sustainable cooling-lubrication strategy for reducing cutting temperature in the turning of C45 steel.

Keywords: C45 Steel, Turning, Cutting Temperature, Minimum Quantity Lubrication, Canola Oil, Taguchi Method

Introduction

Manufacturing industries are increasingly required to improve machining efficiency while reducing environmental impacts and production costs [1, 2]. Conventional flood cooling has long been employed in machining operations to control friction and heat generation; however, the excessive use of cutting fluids creates environmental concerns, disposal challenges, and potential health risks for machine operators [3, 4, 5, 6]. Consequently, sustainable machining technologies have received significant attention from both researchers and industrial practitioners.

Among various sustainable lubrication techniques, Minimum Quantity Lubrication (MQL) has emerged as an effective alternative to conventional flood cooling [7, 8]. MQL delivers a small amount of lubricant directly into the cutting zone in the form of an aerosol, thereby reducing lubricant consumption while maintaining adequate cooling and lubrication performance [9, 10, 11, 12]. In addition, vegetable-based oils have become attractive candidates for MQL applications due to their biodegradability, renewability, and superior lubricating properties [13, 14, 15]. Canola oil, in particular, has demonstrated promising performance in metal cutting operations owing to its high lubricity and environmentally friendly characteristics [16].

C45 steel is widely used in the manufacture of shafts, gears, machine components, and structural parts because of its favorable combination of strength, toughness, and machinability [17, 18]. During the turning of C45 steel, a considerable amount of heat is generated as a result of plastic deformation and friction at the tool–chip interface. Excessive cutting temperature may accelerate tool wear, reduce machining accuracy, and negatively affect product quality [19, 20]. Therefore, controlling cutting temperature is essential for improving machining performance and ensuring process stability.

Previous studies have shown that cutting speed, feed rate, and depth of cut are the primary machining parameters influencing heat generation during turning operations. However, the combined effects of these parameters under canola oil-based MQL conditions have not been sufficiently investigated for C45 steel machining. Therefore, this study aims to evaluate the influence of cutting speed, feed rate, and depth of cut on cutting temperature during the turning of C45 steel under canola oil-based MQL. The Taguchi method and analysis of variance (ANOVA) are employed to identify the most significant factors and determine the optimal machining conditions for minimizing cutting temperature.

Experiment setup

The experiments were conducted on C45 medium-carbon steel under minimum quantity lubrication (MQL) conditions using canola oil as the lubricant. The turning operations were performed on an EMCO Maxxturn 45 CNC lathe equipped with a carbide cutting tool. Cutting temperature was selected as the response variable and measured under different machining conditions. Three machining parameters, namely cutting speed (Vc), feed rate (f), and depth of cut (ap), were considered in this study. A Taguchi L9 orthogonal array was employed to design the experiments with three levels for each factor. The machining parameters and their levels are presented in Table 1, while the experimental results are summarized in Table 2.

Table 1: Machining Parameters and Their Levels

Level	Vc (m/min)	f (mm/rev)	ap (mm)
1	120	0.05	0.5
2	150	0.15	0.75
3	180	0.25	1

Results and Discussion

The experimental design and the corresponding cutting temperature values are presented in Table 2. The measured cutting temperature ranged from 71.2°C to 107.2°C under different machining conditions. The lowest temperature was obtained at a cutting speed of 120 m/min, a feed rate of 0.05 mm/rev, and a depth of cut of 0.5 mm, whereas the highest temperature was recorded at a cutting speed of 180 m/min, a feed rate of 0.25 mm/rev, and a depth of cut of 0.75 mm. In general, cutting temperature increased with increasing cutting speed and feed rate, indicating a higher rate of heat generation during the machining process.

Table 2: Experimental Design and Measured Cutting Temperature

Run	Vc	f	ap	T
1	120	0.05	0.5	71.2
2	120	0.15	0.75	78.4
3	120	0.25	1	85.7
4	150	0.05	0.75	83.1
5	150	0.15	1	91.8
6	150	0.25	0.5	88.5
7	180	0.05	1	94.3
8	180	0.15	0.5	99.6
9	180	0.25	0.75	107.2

The response table for signal-to-noise (S/N) ratios is presented in Table 3. According to the smaller-is-better criterion, cutting speed exhibited the highest Delta value (2.15), followed by feed rate (1.09) and depth of cut (0.48). Therefore, the ranking of factor significance was Vc > f > ap. Fig 1 further confirms this trend, showing a steep decline in S/N ratio with increasing cutting speed, while the influence of depth of cut was relatively small. The optimal parameter combination for minimizing cutting temperature was determined as Vc = 120 m/min, f = 0.05 mm/rev, and ap = 0.5 mm.

Table 3: Response Table for Signal-to-Noise Ratios (Smaller-is-Better)

Level	Vc	f	ap
1	-37.87	-38.31	-38.65
2	-38.86	-39.04	-38.96
3	-40.02	-39.40	-39.14
Delta	2.15	1.09	0.48
Rank	1	2	3

The analysis of variance (ANOVA) results shown in Table 4 reveal that cutting speed was the most influential factor affecting cutting temperature, with an Adj-SS value of 726.73 and a contribution ratio of approximately 76.1%. Feed rate was the second most significant factor, contributing about 19.3%, whereas depth of cut had only a minor effect, contributing approximately 3.0%. The dominance of cutting speed can be attributed to the increased friction and plastic deformation occurring at higher cutting velocities, which leads to greater heat generation in the cutting zone. These findings are consistent with the commonly reported behavior of medium-carbon steel turning operations under MQL conditions.

Table 4: Analysis of Variance (ANOVA) for Cutting Temperature

Source	DF	Adj-SS	Adj-MS	F-Value	P-Value
Vc	2	726.73	363.363	48.06	0.020
f	2	184.43	92.213	12.20	0.076
ap	2	28.25	14.123	1.87	0.349
Error	2	15.12	7.560		
Total	8	954.52			

Table 5: Statistical Performance of the Developed Model

S	R-sq	R-sq(adj)	R-sq(pred)
2.74955	98.42%	93.66%	67.92%

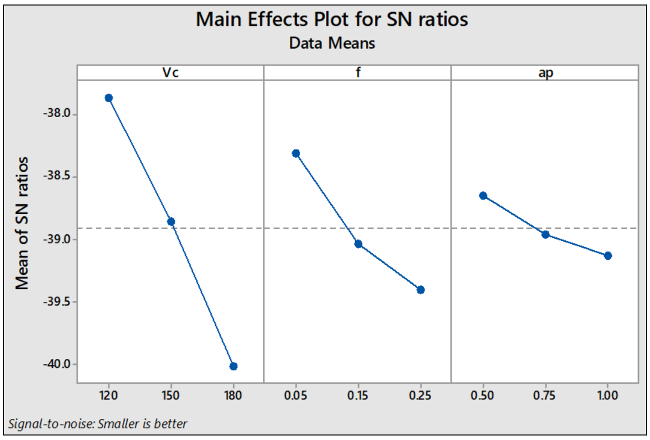

Fig 1: Main Effects Plot for S/N Ratios of Cutting Temperature

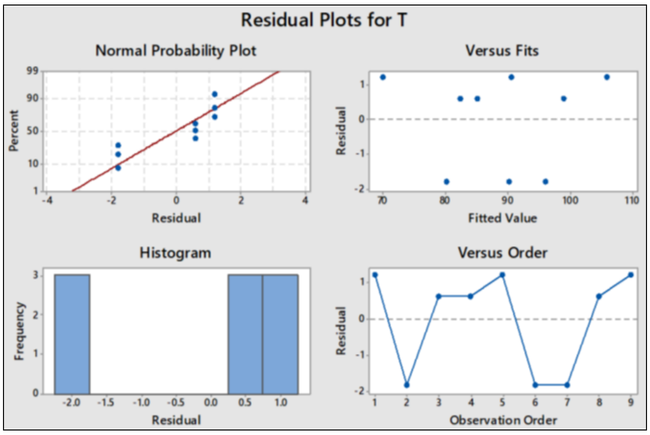

Fig 2: Residual Analysis of the Developed Model

The adequacy of the developed model was evaluated using statistical indicators and residual analysis. As shown in Table 5, the model achieved an R^2 value of 98.42% and an adjusted R^2 value of 93.66%, indicating excellent agreement between the experimental and predicted results. The residual plots presented in Fig 2 show that the residuals are approximately normally distributed and randomly scattered around zero without any obvious pattern. This suggests that the developed model is statistically adequate and can reliably describe the relationship between machining parameters and cutting temperature within the investigated range.

Conclusion

This study investigated the effects of cutting speed, feed rate, and depth of cut on cutting temperature during the turning of C45 steel under canola oil-based MQL conditions using the Taguchi method. The results demonstrated that cutting speed was the most influential factor, contributing approximately 76.1% to the variation in cutting temperature, followed by feed rate and depth of cut. The optimal machining parameters for minimizing cutting temperature were identified as a cutting speed of 120 m/min, a feed rate of 0.05 mm/rev, and a depth of cut of 0.5 mm. The developed model showed good agreement with the experimental results, with an R^2 value of 98.42%. The findings confirm that canola oil-based MQL is an effective and environmentally friendly lubrication strategy for reducing cutting temperature in C45 steel turning operations.

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