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Taguchi Optimization of Cutting Temperature in C45 Steel Turning under Dry and MQL Machining

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Abstract
This study investigates the effects of cooling condition, cutting speed, feed rate, and depth of cut on cutting temperature during the turning of C45 steel using a carbide cutting tool. A Taguchi L8 orthogonal array was employed to design the experiments under dry and minimum quantity lubrication (MQL) conditions. The experimental results were analyzed using signal-to-noise (S/N) ratios and analysis of variance (ANOVA). The results indicated that cooling condition was the most influential factor, contributing 98.1% to the total variation in cutting temperature, followed by cutting speed (1.7%). MQL significantly reduced cutting temperature from 189–215 °C under dry machining to 64–81 °C. The optimal parameter combination for minimizing cutting temperature was identified as MQL cooling, a cutting speed of 120 m/min, a feed rate of 0.1 mm/rev, and a depth of cut of 0.5 mm. The findings demonstrate the effectiveness of MQL in controlling cutting temperature during turning of C45 steel.

Keywords: C45 Steel, Turning, Cutting Temperature, MQL, Taguchi Method, ANOVA

Introduction

Turning is one of the most commonly used machining processes in modern manufacturing due to its ability to produce components with high dimensional accuracy and productivity [1]. During the cutting process, a considerable amount of heat is generated at the tool–workpiece interface as a result of plastic deformation and friction. Excessive cutting temperature can accelerate tool wear, deteriorate surface quality, and reduce machining efficiency. Therefore, controlling cutting temperature is essential for improving machining performance and extending tool life [2, 3].

Traditionally, flood cooling has been widely applied in machining operations to dissipate heat and lubricate the cutting zone [4, 5, 6]. Although this method is effective in reducing cutting temperature, it requires a large volume of cutting fluid, leading to increased operational costs and environmental concerns related to fluid disposal and worker health [7, 8]. As a result, the machining industry has increasingly sought more sustainable cooling and lubrication solutions.

Dry machining has emerged as an environmentally friendly alternative because it eliminates the use of cutting fluids and reduces manufacturing costs [4, 6, 9]. However, the absence of lubrication often results in higher cutting temperatures, increased friction, and accelerated tool wear, particularly at high cutting speeds [10, 11, 12]. To overcome these limitations, Minimum Quantity Lubrication (MQL) has been introduced as a promising technique that delivers a small amount of lubricant directly to the cutting zone. MQL combines the benefits of effective lubrication, reduced fluid consumption, and lower environmental impact while maintaining satisfactory machining performance [13, 14, 15, 16].

C45 steel is widely used in mechanical engineering applications due to its good mechanical properties and machinability [17, 18]. In this study, the effects of cooling condition (Dry and MQL), cutting speed, feed rate, and depth of cut on cutting temperature during the turning of C45 steel using a carbide cutting tool were investigated. A Taguchi L8 orthogonal array was employed to design the experiments, and the results were analyzed using signal-to-noise (S/N) ratios and analysis of variance (ANOVA). The objective of this work is to identify the most influential factors and determine the optimal machining conditions for minimizing cutting temperature.

Experiment setup

The turning experiments were performed on an EMCO Maxxturn 45 CNC lathe using C45 steel workpieces with a hardness of approximately 200 HB. A cemented carbide cutting tool was employed throughout the study.

Four machining parameters were selected: cooling condition (Dry and 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 cutting temperature was measured for each experimental run.

A Taguchi L8 orthogonal array was used to design the experiments. The obtained results were analyzed using signal-to-noise (S/N) ratios and analysis of variance (ANOVA) to determine the significance and contribution of each machining parameter.

Results and Discussion

Table 1: Experimental design matrix and measured cutting temperature

Run	A	Vc (m/min)	f (mm/rev)	ap (mm)	A	B	C	D	T (°C)
1	Dry	120	0.1	0.5	1	1	1	1	189.1
2	Dry	120	0.2	1	1	1	2	2	196.7
3	Dry	180	0.1	1	1	2	1	2	210.4
4	Dry	180	0.2	0.5	1	2	2	1	215.4
5	MQL	120	0.1	1	2	1	1	2	63.6
6	MQL	120	0.2	0.5	2	1	2	1	65.6
7	MQL	180	0.1	0.5	2	2	1	1	76.8
8	MQL	180	0.2	1	2	2	2	2	81.4

Table 1 presents the experimental design and the corresponding cutting temperature values obtained under different machining conditions. The results show that cutting temperature ranged from 63.6 to 215.4 °C. Under dry machining, the temperature varied between 189.1 and 215.4 °C, whereas MQL significantly reduced the temperature to 63.6–81.4 °C. This indicates that the application of MQL effectively suppresses heat generation in the cutting zone.

Table 2: ANOVA results for cutting temperature

Source	DF	Adj-SS	Adj-MS	F-Value	P-Value	C%
Cooling	1	34348.2	34348.2	5250.68	0.000	98.1
Vc	1	595.1	595.1	90.97	0.002	1.7
f	1	46.1	46.1	7.04	0.077	0.13
ap	1	3.4	3.4	0.52	0.524	0.01
Error	3	19.6	6.5			0.06
Total	7	35012.4				100

The ANOVA results presented in Table 2 confirm that cooling condition was the dominant factor, contributing 98.1% to the total variation in cutting temperature. Cutting speed was the second most influential factor with a contribution of 1.7%, while feed rate and depth of cut had negligible effects. In addition, the developed model exhibited excellent predictive capability with an R^2 value of 99.94% (Table 3).

Table 3: Regression model summary statistics

S	R-sq	R-sq(adj)	R-sq(pred)
2.55767	99.94%	99.87%	99.60%

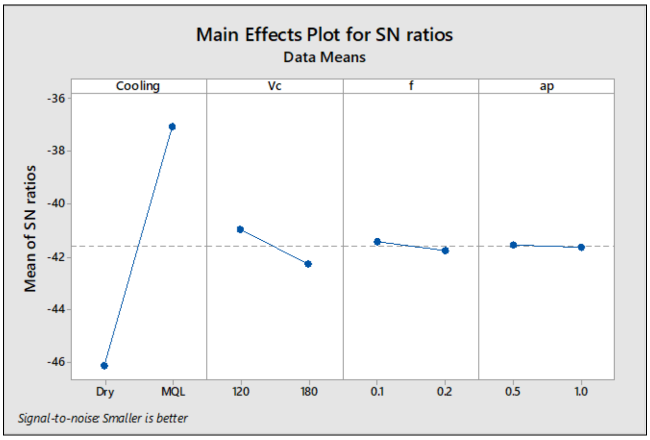

Fig 1: Main effects plot for S/N ratios of cutting temperature

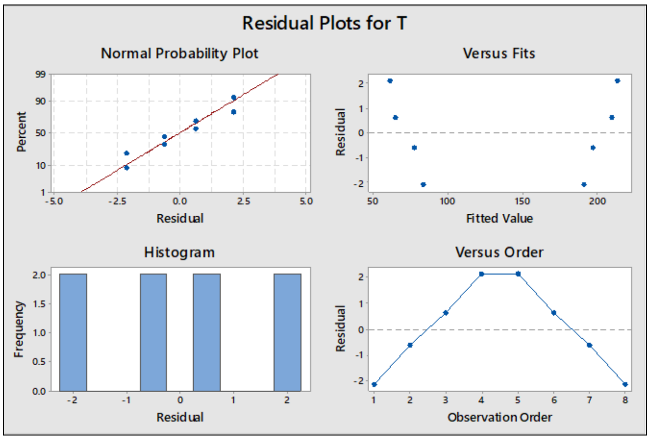

Fig 2: Residual plots of the developed model for cutting temperature

The main effects plot for S/N ratios shown in Fig 1 reveals that the cooling condition had the greatest influence on cutting temperature, followed by cutting speed, feed rate, and depth of cut. The optimal parameter combination for minimizing cutting temperature was identified as MQL cooling, a cutting speed of 120 m/min, a feed rate of 0.1 mm/rev, and a depth of cut of 0.5 mm.

The residual plots shown in Fig 2 indicate that the residuals were approximately normally distributed and randomly scattered, demonstrating the adequacy of the developed model.

Conclusion

This study investigated the effects of cooling condition, cutting speed, feed rate, and depth of cut on cutting temperature during the turning of C45 steel using a carbide cutting tool. The results demonstrated that MQL significantly reduced cutting temperature compared with dry machining. Taguchi analysis identified the optimal machining parameters as MQL cooling, a cutting speed of 120 m/min, a feed rate of 0.1 mm/rev, and a depth of cut of 0.5 mm. ANOVA revealed that cooling condition was the most influential factor, contributing 98.1% to the total variation in cutting temperature, followed by cutting speed. The developed model exhibited excellent predictive accuracy with an R^2 value of 99.94%. The findings confirm the effectiveness of MQL in controlling cutting temperature and provide useful guidance for sustainable turning of C45 steel.

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