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Optimizing the Cutting Parameters to Improve the Surface Roughness in Hard Turning of SKD11 Steel Machining using the Taguchi Method

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Abstract
Surface roughness is a crucial parameter for evaluating the quality of metal cutting processes. In this study, the Taguchi method is employed to identify the optimal machining parameters to achieve the minimum surface roughness in machining hard steel SKD11. Three fundamental parameters of the cutting regime are selected: Cutting speed, cutting depth, and feed rate. Each parameter is divided into three levels: Low, medium, and high. The experimental design is constructed based on the L9 array of the Taguchi method. The results indicate that the feed rate has the greatest influence on machining surface roughness, followed by cutting depth and cutting speed, respectively. An optimal cutting regime is proposed to achieve the minimum surface roughness.

Keywords: Hard Turning, Taguchi Method, Surface Roughness, Optimization, SKD 11

Introduction
Hard machining has found extensive application in mechanical processing owing to its numerous advantages. These benefits encompass enhanced geometric accuracy, improved surface quality of finished products, reduced labor costs [1], minimized burr formation, more efficient chip disposal, heightened stability, simplified tooling [2], and enhanced flexibility in process design [3, 4, 5]. Nowadays, hard machining is widely used in production for many machining methods such as turning, milling, drilling...

Surface roughness serves as a crucial indicator for assessing the quality of mechanical products. Various factors contribute to surface roughness, including cutting tool properties (such as material, shape, run-out error, and nose radius), workpiece characteristics (such as diameter, hardness, and length), cutting phenomena (including acceleration, vibrations, chip formation, friction in the cutting zone, and cutting force variation), and machining parameters (such as process kinematics, cooling fluid, step over, tool angle, depth-of-cut, feed rate, and cutting speed) [6, 7]. In any machining operation, selecting appropriate cutting parameters tailored to the material of the workpieces stands as a pivotal step in ensuring manufacturing quality. The Taguchi technique, employing designed experiments, stands as a widely utilized method for optimizing cutting parameters and predicting surface roughness. Significant research has been conducted exploring the impact of cutting parameters on surface roughness, utilizing the Taguchi method to drive insights and optimizations [8, 9].

In this study, the optimization process is conducted using the Taguchi method to achieve the minimum surface roughness in hard turning of SKD11 steel. Three cutting parameters (cutting speed, depth of cut, and feed rate) are investigated to determine their influence on the output response.

Experiment setup
The experiments are conducted using the L9 orthogonal array of the Taguchi method. All experiments are performed on an EMCO Maxxturn 45 CNC lathe. The cutting tool used is a CBN insert tool. The workpiece is heat-treated to achieve a hardness of 50HRC and has an initial diameter of 35mm. Surface roughness is measured immediately after each experiment using a Mitutoyo SJ-401 roughness measuring instrument. The machining process does not utilize coolant (dry machining). The cutting parameters, including cutting speed, depth of cut, and feed rate, are categorized into three levels: Low, medium, and high. Surface roughness is determined at three different positions and averaged for analysis.

Results and discussions

Table 1 presents the results of the conducted experiments. The surface roughness values range from 0.88 (experiment number 8) to 1.36 (experiment number 7). Utilizing Minitab v17, the Signal to Noise (S/N) ratio results and variance analysis are provided.

Table 1: Experimental Result

S. No	v (m/min)	d (mm)	f (mm/rev)	Ra (µm)	S/N
1	60	0.1	0.1	1.03	-0.25674
2	60	0.2	0.2	1.11	-0.90646
3	60	0.3	0.3	1.22	-1.7272
4	80	0.1	0.2	1.16	-1.28916
5	80	0.2	0.3	1.21	-1.65571
6	80	0.3	0.1	0.93	0.630341
7	100	0.1	0.3	1.36	-2.67078
8	100	0.2	0.1	0.88	1.110347
9	100	0.3	0.2	1.08	-0.66848

In Table 2, the average S/N response values related to surface roughness are displayed. Upon thorough analysis, it becomes apparent that the third level of cutting speed, the second level of cutting depth, and the first level of feed rate emerge as the highest-ranking levels for each respective parameter. Consequently, the optimal experimental condition is established as (3-2-1). This ranking underscores the significant impact of feed rate on surface roughness, with cutting depth following closely in influence.

Table 2: Response for the S/N ratio

Level	v	d	f
1	-0.9635	-1.4056	**0.4946**
2	-0.7715	**-0.4839**	-0.9547
3	**-0.7430**	-0.5884	-2.0179
Delta	0.2205	0.9216	2.5125
Rank	3	2	1

Table 3 serves as a concise summary of the variance analysis findings. According to the ANOVA table, it becomes evident that the feed rate within the solution emerges as the most significant factor, contributing a substantial 83.9% to the overall impact on the surface roughness. Following closely is the depth of cut, which accounts for 14% of the variation observed. Notably, input factors with p-values below 0.05 signify their statistically significant influence on the outcome. Furthermore, with an impressive R-Squared value of 98.17%, it is observed that a remarkable 98.17% of the variability in surface roughness can be effectively explained by the considered input factors. This underscores the robustness of the model and the degree to which these factors contribute to the observed outcomes.

Table 3: The ANOVA table

Source	DF	Adj-SS	Adj-MS	F-Value	P-Value	C%
v	2	0.000622	0.000311	0.19	0.841	0.35
d	2	0.025089	0.012544	7.63	0.116	14.0
f	2	0.150689	0.075344	45.82	0.021	83.9
Error	2	0.003289	0.001644	-	-	-
Total	8	0.179689	-	-	-	-
R-sq = 98.17%						

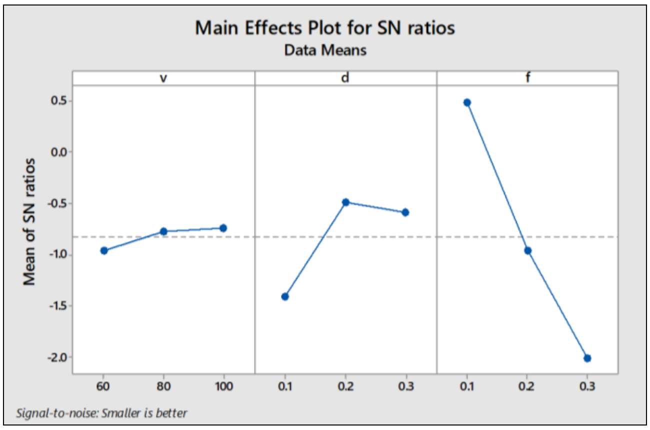

Fig 1: The S/N ratio plot

The Response Signal-to-Noise (S/N) analysis depicted in Fig 1 reveals the optimal cutting conditions for attaining the finest surface roughness. These conditions entail a cutting feed of 100m/min, a cutting depth of 0.2 mm, and a feed rate of 0.1mm/rev. This optimal condition corresponds to experiment number 8. In this experiment, the achieved surface roughness result is 0.88 µm, which is the smallest roughness value obtained throughout the entire experiment. This demonstrates the reliability of the model.

Conclusion

In this study, the optimization process is conducted using the Taguchi method to achieve the minimum surface roughness in hard turning of SKD11 steel. Three cutting parameters (cutting speed, depth of cut, and feed rate) are investigated to determine their influence on the output response. Major discoveries can be encapsulated as follows:

- The optimal condition for the minimum surface roughness is level 3 for cutting speed, level 2 for cutting depth, and level 1 for feed rate.
- The feed rate is the dominant influencing factor determining surface roughness, accounting for over 83% of the total impact, followed by cutting depth with 14% of the total impact. Cutting speed has a negligible influence.
- The model provided exhibits high reliability, indicated by an R-squared value of 98.17%.

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