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Optimization of Cutting Parameters for Surface Grinding of AISI 420B Steel

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Abstract
Surface roughness significantly influences the performance and fatigue life of machine components. This study aims to determine the optimal cutting parameters for the surface grinding of AISI 420B steel. A total of 15 experiments were designed using a Box-Behnken response surface design. In each experiment, three input cutting parameters-workpiece velocity, feed rate, and depth of cut—were varied, and the resulting surface roughness was measured. The individual and interactive effects of these cutting parameters on surface roughness were systematically analyzed. A mathematical regression model was established to describe the relationship between surface roughness and the cutting parameters. Subsequently, a Genetic Algorithm (GA) was employed to solve the optimization problem to minimize surface roughness.
Keywords: *Surface grinding, AISI 420B steel, surface roughness, optimization, Genetic Algorithm (GA).*

I. Introduction

In mechanical machining, grinding is the most widely used finishing method for components requiring high dimensional accuracy and low surface roughness. Surface grinding is extensively applied across various industrial sectors—such as automotive, mining, and mold/die manufacturing—to machine planar surfaces. Among numerous indicators used to evaluate the grinding process (e.g., surface roughness, cutting force, cutting temperature, surface microstructural integrity, and material removal rate), surface roughness is the most commonly adopted. This is because surface roughness directly affects the service life and operational reliability of machine parts, and its measurement is generally simpler and more straightforward than measuring cutting forces or thermal profiles. To achieve minimal surface roughness, numerous studies have optimized cutting parameters when surface grinding various engineering materials, such as En24 steel, ШХ15 steel, ASTM A36 steel, 90CrSi steel, AISI 316 stainless steel, and Mild steel.

AISI 420B is a wear-resistant stainless steel designated under the Japanese JIS G4303 standard. It corresponds to AISI 440C under ASTM A276 (USA) and 9Cr18Mo under GB standard (China). This material is widely used to manufacture high-precision components subjected to heavy mechanical loads in severe corrosive or strongly oxidizing environments without lubrication, as well as stamping dies.

This study investigates the optimization of cutting parameters in surface grinding AISI 420B steel to achieve minimal surface roughness. Section 2 describes the experimental setup and response surface design. Section 3 presents the experimental results, statistical analysis, and optimization outcomes. Finally, the main conclusions are summarized in Section 4.

II. Materials and Methods

The workpiece material used in this study was AISI 420B stainless steel. Its primary chemical composition is given in Table 1. The dimensions of the workpiece specimens were 50mm, 30mm, 10mm (length, width, height).

Table 1. Chemical composition of AISI 420B steel (wt.%)

C(%)	Si (%)	Mn (%)	P (%)	S (%)	Cr (%)	Ni (%)	Mo (%)
0.8 - 1.2	≤ 1.16	≤ 1.10	≤ 0.04	≤ 0.04	11 – 14.5	≤ 0.06	≤0.74

The experimental design was formulated using a Box-Behnken design (BBD), a widely adopted response surface methodology for optimization studies. Under this design, each input parameter was tested at three levels coded as -1, 0, and 1. The levels for the input cutting parameters were selected based on published literature and are summarized in Table 2. The full experimental matrix comprising 15 runs is presented in Table 3.

Table 2. Cutting parameters and their levels

Parameter	Unit	Code symbol	Real symbol	Value at level		
				-1	0	1
Workpiece vevlocity	m/ min	x_1	V	5	8	11

Feed-rate	mm/ stroke	x_2	S	3	5	7
Depth of cut	mm	x_3	t	0.01	0.015	0.02

Table 3. Experimental matrix

Exp.	Code value			Real value		
	x_1	x_2	X_3	V (m/min)	S (mm/stroke)	t (mm)
1	-1	0	-1	5	5	0.01
2	0	-1	1	8	3	0.02
3	0	-1	-1	8	3	0.01
4	0	1	-1	8	7	0.01
5	1	-1	0	11	3	0.015
6	-1	0	1	5	5	0.02
7	0	0	0	8	5	0.015
8	0	1	1	8	7	0.02
9	0	0	0	8	5	0.015
10	0	0	0	8	5	0.015
11	1	0	-1	11	5	0.01
12	-1	1	0	5	7	0.015
13	1	1	0	11	7	0.015
14	1	0	1	11	5	0.02
15	-1	-1	0	5	3	0.015

III. Results and Discussion

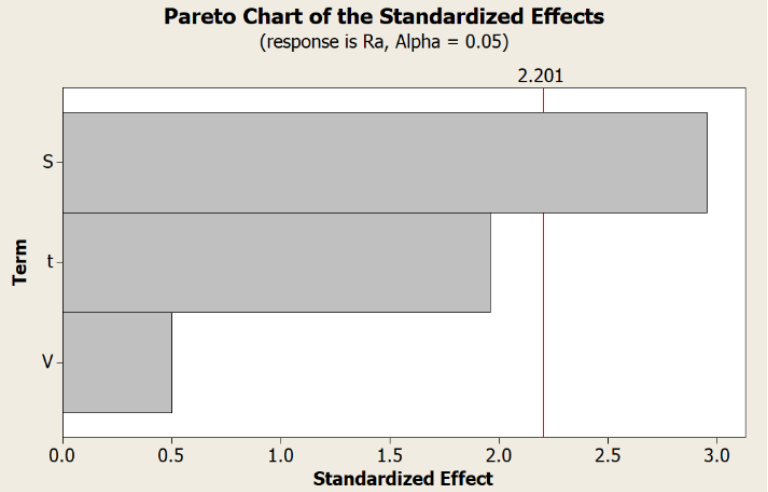
The experimental runs were conducted according to the randomized matrix in Table 3, and the measured surface roughness (Ra) values are shown in Table 4.

Table 4. Experimental results for surface roughness (Ra)

Exp.	Cutting parameter			Ra (μm)
	V (m/min)	S (mm/stroke)	t (mm)	
1	5	7	0.015	0.605
2	11	7	0.015	0.917
3	8	5	0.015	0.760
4	8	7	0.02	1.016
5	8	5	0.015	0.689
6	8	3	0.01	0.467
7	8	7	0.01	0.579
8	11	3	0.015	0.573
9	11	5	0.01	0.608
10	8	5	0.015	0.656
11	11	5	0.02	0.637
12	5	3	0.015	0.452
13	5	5	0.01	0.764

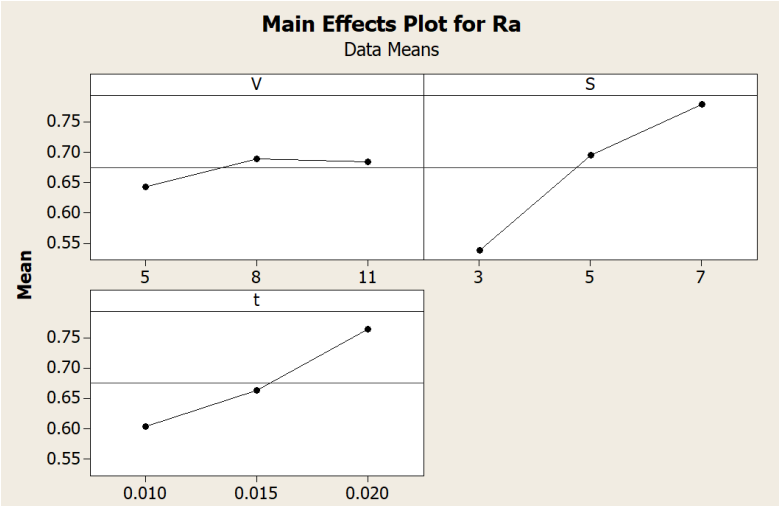
14	8	3	0.02	0.657
15	5	5	0.02	0.750

Minitab 16 statistical software was utilized to evaluate the relative influence of each parameter on surface roughness. The Pareto chart of standardized effects is shown in Figure 3.

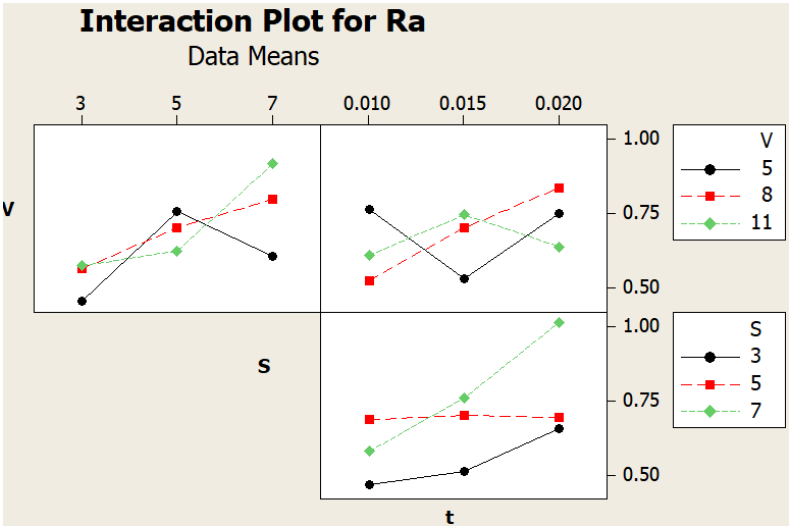


(Figure 3. Pareto chart of standardized effects on surface roughness)

As observed in Figure 3, the feed rate (S) has the most statistically significant effect on surface roughness, followed by the depth of cut (t), whereas the workpiece velocity (V) exhibits the lowest effect.
Figures 4 and 5 illustrate the main effects and the two-factor interaction effects of the cutting parameters on surface roughness, respectively.



(*Figure 4. Main effects plot for surface roughness Ra)*



(Figure 5. Interaction plot for surface roughness Ra)

As shown in the main effects plot (Figure 4), increasing any of the cutting parameters leads to an increase in surface roughness. Notably, increasing either the feed rate or depth of cut results in a sharp rise in surface roughness.

The interaction plot (Figure 5) reveals complex interactive behaviors among parameter pairs:

- At V = 5m/min, increasing S from 3 to 5mm/stroke increases Ra, but further increasing S to 7mm/stroke causes a decrease in Ra.
- At V = 8m/min and 11m/min, increasing S consistently increases Ra.
- At V = 5m/min, increasing t from 0.01 to 0.015mmdecreases Ra, whereas further increasing t to 0.02mm significantly increases Ra.
- At V = 8m/min, increasing t causes a rapid increase in Ra.
- At V = 11m/min, increasing t from 0.01to 0.015mm increases Ra, but a higher depth of cut (0.02mm reduces Ra).
- At S = 3mm/stroke, increasing t consistently increases Ra. However, at S = 5mm/stroke, changes in t have a negligible impact on Ra.

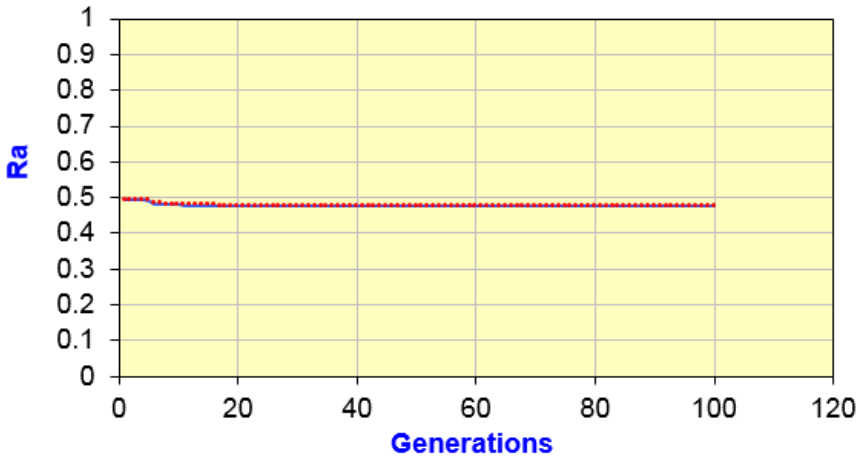
These findings highlight the intricate, non-linear dependencies of surface roughness on cutting parameters and their interactions, highlighting the necessity of mathematical optimization.

Based on the experimental data, a quadratic regression model for surface roughness was derived as follows (Eq. 1):

$$R_a = 0.6817 + 0.0051 \cdot V - 0.0021 \cdot S - 39.21 \cdot t - 0.003 \cdot V^2 - 0.0093 \cdot S^2 + 621.68 \cdot t^2 + 0.0079 \cdot V \cdot S + 0.7167 \cdot V \cdot t + 6.175 \cdot S \cdot t \quad (1)$$

To optimize the process, a Genetic Algorithm (GA) was applied. The GA parameters were set as follows: population size = 150, maximum generations = 100, crossover probability = 0.25, mutation probability = 0.05, and mutation parameter = 4.

Figure 8 depicts the convergence history of surface roughness across successive generations during GA optimization. The optimal solution yielded a minimum surface roughness of Ra = 0.4748(μm), achieved at V = 10.99m/min, S = 3.00mm/stroke, and t = 0.011mm.



(Figure 8. GA convergence curve for surface roughness optimization)

IV. Conclusions

In this study, surface grinding experiments on AISI 420B steel were conducted by varying workpiece velocity, feed rate, and depth of cut. A Genetic Algorithm was successfully implemented to minimize surface roughness. The main conclusions are as follows:

- Feed rate is the most dominant factor influencing surface roughness, followed by the depth of cut, while workpiece velocity has the least influence.
- To achieve minimum surface roughness (Ra = 0.4748(μm), the optimal cutting conditions are: workpiece velocity V = 10.99m/min, feed rate S = 3.00mm/stroke, and depth of cut t = 0.011mm.

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