International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 15, Issue 6 [June 2026] PP: 58-62

Optimization of Cutting Parameters when Turning 90CrSi Steel based on Surface Roughness Criteria

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Abstract
This study investigates the effects of three cutting parameters, including cutting speed, feed rate, and depth of cut, on surface roughness when turning 90CrSi steel. An experimental process was carried out with a total of 15 experiments designed using the Box-Behnken method. A 3-axis CNC lathe and TNMG 160408-MA VP15TF cutting inserts were utilized during the experimentation. In each experiment, the values of the three parameters—cutting speed, feed rate, and depth of cut—were varied simultaneously. Surface roughness was also measured on each experimental specimen for every run. Minitab software was used to analyze the influence of the cutting parameters on surface roughness. The optimal values of the cutting parameters were also determined to ensure the minimum surface roughness of the machined surface.
Keywords: *cutting parameters, surface roughness, 90CrSi steel, optimization*

Date of Submission: 06-06-2026 Date of acceptance: 16-06-2026

I. Introduction

The turning method plays an especially important role and is one of the most common conventional cutting operations in the mechanical manufacturing and engineering industry [1-3]. With its capability to machine a diverse range of external and internal surfaces of revolution, this method contributes significantly to shaping and finishing the vast majority of common machine parts [4-5].

In the process of evaluating the quality of turned products, surface roughness is one of the core and decisive technical parameters. This index directly affects the stable operation of the component, as an excessively rough surface increases friction and kinetic energy loss during operation [6, 7]. Furthermore, low roughness increases the actual contact area between mating surfaces, thereby significantly enhancing wear resistance and extending the lifespan of the product. Particularly, surface irregularities on the machined surface are often areas of high stress concentration; effective control of roughness eliminates these hazardous points, helping the component resist crack formation and enhancing fatigue strength under cyclic loading [8, 9].

90CrSi steel (or 90ChSi according to Russian standards) is a cold-work alloy tool steel, very commonly used in the manufacturing and machining industry. With a high carbon content (approximately 0.9%) combined with alloying elements such as Chromium (Cr) and Silicon (Si), this steel possesses high hardness, good wear resistance, and stable thermal stability after heat treatment. Thanks to these superior mechanical and physical properties, 90CrSi steel is widely applied to manufacture low-productivity or low-speed cutting tools such as drill bits, taps, threading dies, broaches, as well as various turning tools and form milling cutters. In addition, it is an ideal material for manufacturing high-wear-resistant components in molds, rolling shafts, rollers, cutting discs, or measuring instruments requiring high precision and dimensional stability over time.

This study was conducted to determine the optimal values of cutting parameters when turning this type of steel to ensure the minimum surface roughness value.

II. Experimental Design

90CrSi steel workpieces with a diameter and length of 28 (mm) and 250 (mm), respectively, were used during the experimentation. In this study, turning inserts with the designation TNMG 160408-MA VP15TF from Mitsubishi Materials (Japan) were utilized. This is a versatile cutting insert, optimally designed for machining alloy steels and high-hardness steels after heat treatment. A 3-axis lathe designated LYNX 2100LYA from DN Solutions (South Korea) will be used in the experimental process. An SJ301 roughness tester from Mitutoyo (Japan) was used to measure surface roughness. Figure 1 shows a photograph of the basic components of the experimental system.

a) b) c) d)

a) experimental workpiece; b) cutting tool; c) CNC lathe; d) surface roughness tester

Figure 1. Experimental system

An experimental matrix consisting of 15 experiments was established using the Box-Behnken method, as summarized in Table 1. The values of the cutting parameters in this table were selected based on their values in recently published studies under experimental conditions similar to those conducted in this research [10, 11].

Table 1. Experimental matrix and results

Trial.	Code value			Real value			Ra (μm)
	V	S	t	V (m/min)	S (mm/rev)	t (mm)	
1	-1	-1	0	80	0.05	0.4	0.907
2	1	-1	0	160	0.05	0.4	1.247
3	-1	1	0	80	0.09	0.4	1.098
4	1	1	0	160	0.09	0.4	1.766
5	-1	0	-1	80	0.07	0.3	1.591
6	1	0	-1	160	0.07	0.3	2.647
7	-1	0	1	80	0.07	0.5	0.99
8	1	0	1	160	0.07	0.5	1.566
9	0	-1	-1	120	0.05	0.3	1.247
10	0	1	-1	120	0.09	0.3	1.708
11	0	-1	1	120	0.05	0.5	0.895
12	0	1	1	120	0.09	0.5	1.331
13	0	0	0	120	0.05	0.4	1.003
14	0	0	0	120	0.05	0.4	1.006
15	0	0	0	120	0.05	0.4	1.008

III. Results and Discussion

The final column of Table 1 summarizes the surface roughness values for each experiment. Utilizing Minitab software, graphs showing the influence of the cutting parameters on surface roughness were plotted, as presented in Figure 2 and Figure 3.

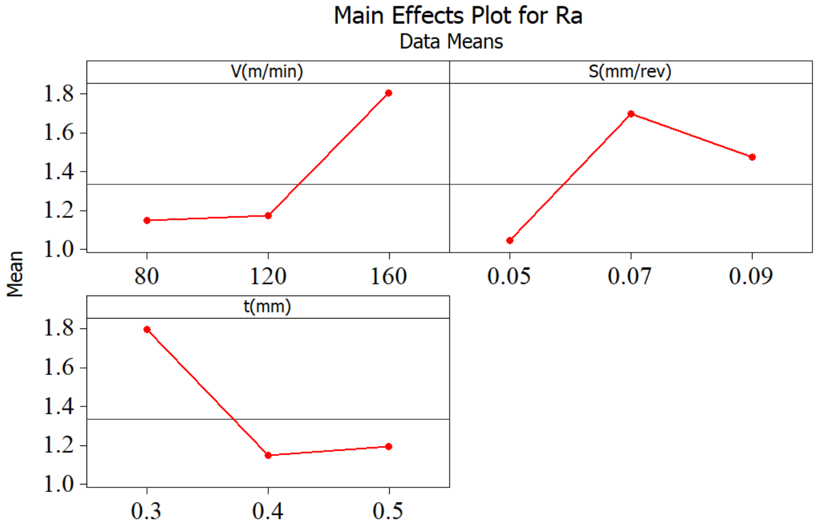

Figure 2. Effect of cutting parameters on surface roughness

Observing Figure 2, it is noticeable that when the cutting speed increases from 80 (m/min) to 120 (m/min), the surface roughness remains almost unchanged, but if the cutting speed continues to increase, the surface roughness increases very rapidly. When increasing the feed rate from 0.05 (mm/rev) to 0.07 (mm/rev), the surface roughness increases rapidly, but continuing to increase the feed rate causes the surface roughness to decrease relatively quickly. Regarding the depth of cut, increasing the value of this parameter from 0.3 (mm) to 0.4 (mm) causes a rapid decrease in surface roughness, but continuing to increase this parameter leads to an increase in surface roughness, though at a slower rate.

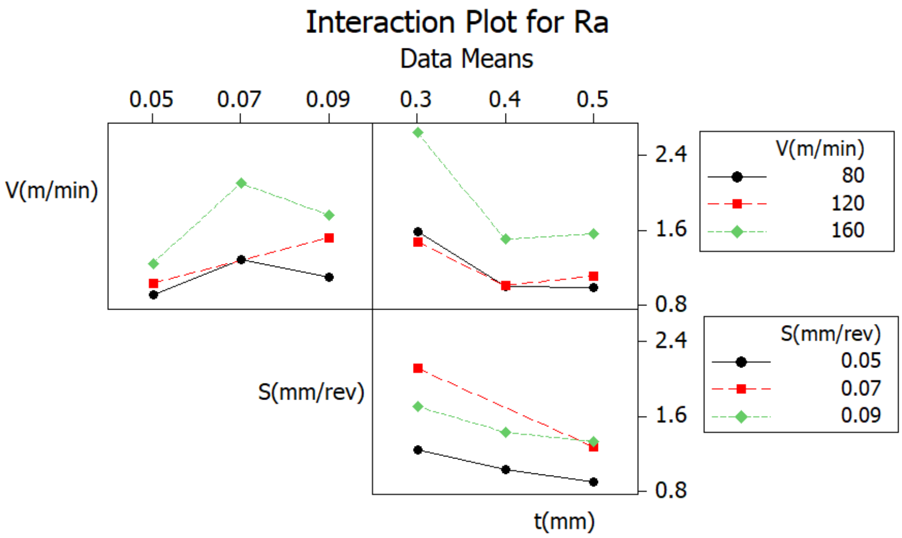

Figure 3. Interactive effects of cutting parameters on surface roughness

Observing Figure 3, it is found that at a cutting speed of 80 (m/min), if the feed rate increases from 0.05 (mm/rev) to 0.07 (mm/rev), the roughness increases, but if the feed rate continues to increase, the surface roughness decreases. In the case where the cutting speed is 120 (m/min), increasing the feed rate will increase the surface roughness. For the case where the cutting speed is 160 (m/min), if the feed rate increases from 0.05 (mm/rev) to 0.07 (mm/rev), the surface roughness increases, but if the feed rate continues to increase, the surface roughness decreases. In all three cases of cutting speeds equal to 80, 120, and 160 (m/min), if the depth of cut increases from 0.3 (mm) to 0.4 (mm), the surface roughness decreases. However, if the depth of cut increases from 0.4 (mm) to 0.5 (mm), the surface roughness remains almost unchanged. In all three cases of feed rates, an increase in the depth of cut leads to a decrease in surface roughness.

Several analyses performed when examining the graphs in Figure 2 and Figure 3 show that the cutting parameters have a very complex influence on surface roughness. To achieve low surface roughness in machining, determining the optimal values of the cutting parameters is essential. Figure 4 illustrates the optimization chart of cutting parameters based on surface roughness criteria.

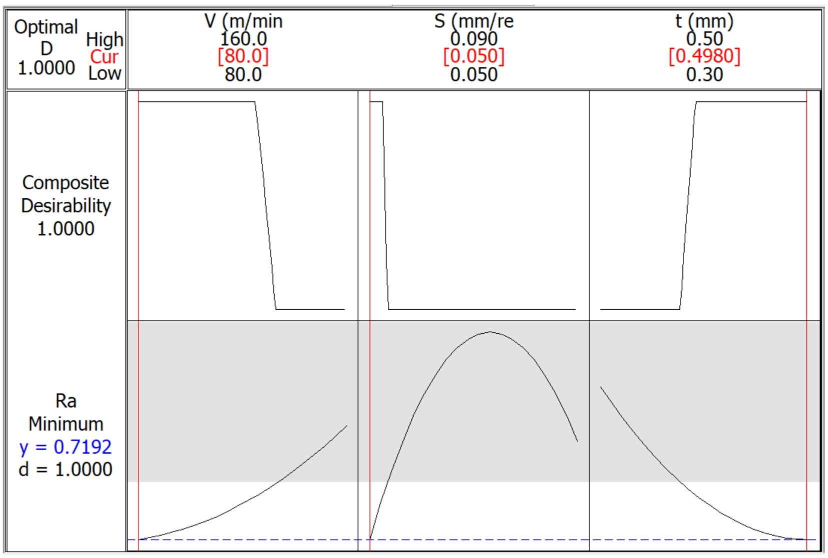

Figure 4. Optimization plot

According to the results illustrated in Figure 4, the optimal value of the cutting speed is 80 (m/min), the feed rate is 0.05 (mm/rev), and the depth of cut is 0.489 (mm). With a desirability function equal to 1, it demonstrates that the probability of achieving the optimal values of the cutting parameters is 100%. Corresponding to this optimal condition, the surface roughness will reach its minimum value of 0.7192 (µm).

Experimental verification of the optimal results was conducted on 3 steel workpieces identical to the workpieces previously used when performing the matrix experiments shown in Table 1. The average surface roughness value when testing these 3 steel specimens was 0.7645 (µm). Thus, the discrepancy in surface roughness when solving the optimization problem compared to the verification experiment is only 0.0453 (µm), corresponding to 5.92%.

IV. Conclusion

When using the TNMG 160408-MA VP15TF cutting insert to turn 90CrSi steel with the cutting speed adjusted from 80 to 160 (m/min), the feed rate adjusted from 0.05 to 0.09 (mm/rev), and the depth of cut adjusted from 0.3 to 0.5 (mm), the optimal values of these parameters are 80 (m/min), 0.05 (mm/rev), and 0.489 (mm), respectively. Corresponding to these optimal values of the cutting parameters, the surface roughness will reach a minimum value of 0.7645 (µm).

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