

## Optimization of Machining Parameters for Minimum Surface Roughness in Turning of Aluminium- Magnesium Alloy Using a 0.4 mm Nose Radius Tool: A Taguchi Approach

Gaith Ebrahim Abdulhadi <sup>1\*</sup>, Ali Ahmed Ali Musbah <sup>2</sup>

<sup>1,2</sup> Faculty of Engineering, Bani Waleed University, Bani Walid, Libya

\*Email (for reference researcher): [alimusbah.aa@gmail.com](mailto:alimusbah.aa@gmail.com)

تحسين متغيرات التشغيل لتحقيق أقل خشونة سطحية في خراطة سبائك الألومنيوم-المغنيسيوم باستخدام أداة نصف قطر راسه 0.4 مم: منهجية تاجوشي

غيث إبراهيم عبدالهادي<sup>1\*</sup>، علي احمد علي مصباح<sup>2</sup>  
<sup>2,1</sup> كلية الهندسة، جامعة بني وليد، بني وليد، ليبيا

Received: 12-12-2025; Accepted: 08-02-2026; Published: 26-02-2026

### Abstract:

This study presents a systematic investigation to optimize the turning parameters in order to minimize surface roughness (Ra) of an Aluminum–Magnesium alloy (Al3Mg) using a CNC turning machine and a cutting tool insert with a 0.4 mm nose radius. The work employs the Taguchi Design of Experiments (DOE) methodology to analyze the effects of three main control factors (cutting speed, feed rate, and depth of cut), each at three levels. An L9 orthogonal array was used to design the experiments. In this study, the “smaller-the-better” signal-to-noise (S/N) ratio was utilized as the performance metric to evaluate surface roughness. Analysis of Variance (ANOVA) was performed to determine the statistical significance and percentage contribution of the turning parameters. The optimal parameter combination for the 0.4 mm nose radius tool was: Cutting Speed (B3) = 900 rpm, Feed Rate (A1) = 0.3 mm/rev, and Depth of Cut (C2) = 1.0 mm. The ANOVA results indicated that feed rate was the most significant contributing factor, accounting for 88.97% of the total variation in surface roughness, followed by cutting speed (4.44%) and depth of cut (3.14%). The predicted surface roughness under optimal conditions was 508.21  $\mu\text{m}$ . This study demonstrates the effectiveness of the Taguchi methodology for process optimization, leading to improved surface roughness with a minimal number of experiments.

**Keywords:** Taguchi method; surface roughness; CNC turning; ANOVA; cutting parameters; Aluminum–Magnesium alloy.

### المخلص:

تقدم هذه الدراسة تحقيقاً منهجياً يهدف إلى تحسين معاملات الخراطة من أجل تقليل خشونة السطح (Ra) لسبيكة الألومنيوم-المغنيسيوم (Al3Mg) باستخدام ماكينة خراطة CNC وأداة قطع ذات نصف قطر أنف يبلغ 0.4 مم. اعتمدت الدراسة على منهجية تاجوشي لتصميم التجارب (DOE) لتحليل تأثير ثلاثة عوامل تحكم رئيسية (سرعة القطع، معدل التغذية، وعمق القطع)، كل منها عند ثلاثة مستويات. تم استخدام مصفوفة L9 المتعامدة لتصميم التجارب. وفي هذه الدراسة، استُخدم معيار نسبة الإشارة إلى الضوضاء (S/N) من نوع «الأصغر هو الأفضل» كمقياس أداء لتقييم خشونة السطح. كما تم إجراء تحليل التباين (ANOVA) لتحديد الدلالة الإحصائية ونسبة مساهمة معاملات الخراطة.

كانت التركيبة المثلى للمعاملات باستخدام أداة ذات نصف قطر أنف 0.4 مم كما يلي: سرعة القطع (B3) = 900 دورة/دقيقة، معدل التغذية (A1) = 0.3 مم/دورة، وعمق القطع (C2) = 1.0 مم. وأظهرت نتائج تحليل التباين أن معدل التغذية كان العامل الأكثر تأثيراً، حيث ساهم بنسبة 88.97% من التباين الكلي في خشونة السطح، يليه سرعة القطع بنسبة (4.44%) ثم عمق القطع بنسبة (3.14%). وبلغت قيمة خشونة السطح المتوقعة في ظل الظروف المثلى 508.21 ميكرومتر. وتبرز هذه الدراسة فاعلية منهجية تاجوشي في تحسين العمليات، مما يؤدي إلى تحسين خشونة السطح مع تقليل عدد التجارب إلى الحد الأدنى.

**الكلمات المفتاحية:** طريقة تاجوشي؛ خشونة السطح؛ الخراطة باستخدام CNC؛ تحليل التباين؛ معاملات القطع؛ سبيكة الألومنيوم-المغنيسيوم.

### Introduction

Surface roughness is a critical quality characteristic in machining operations, directly influencing the functional performance, fatigue life, and aesthetics of manufactured components [1]. In turning processes, surface finish is governed by a complex interaction of numerous parameters, including cutting tool geometry, workpiece material, and cutting conditions [2]. Optimizing these parameters traditionally requires extensive and costly experimentation. The Taguchi method offers a robust and efficient statistical framework for designing experiments, analyzing data, and optimizing processes in terms of performance, quality, and cost [3].

This research focuses on applying the Taguchi method to determine the optimal combination of cutting speed, feed rate, and depth of cut for minimizing the surface roughness of Al3Mg alloy during turning, specifically using a cutting tool with a 0.4 mm nose radius. The Al3Mg alloy was selected due to its industrial significance and its susceptibility to surface degradation during machining [4].

### Problem Statement

Machining process parameters such as cutting speed, feed rate, and depth of cut significantly influence the process and play a major role in determining the quality of the surface finish.

For this reason, an investigation was carried out on an Aluminum–Magnesium alloy (Al3Mg) workpiece to obtain optimum surface finish along with a high material removal rate.

### Methodology

The turning experiments were conducted according to Taguchi's L9 orthogonal array (OA), which consists of 9 experimental runs with 3 columns at three levels. The first column was assigned to cutting speed (A), the second column to feed rate (B), and the third column to depth of cut (C). Three process parameters were varied at three discrete levels.

Each experimental run was replicated three times, and the corresponding response values for surface roughness (Ra) were recorded. The surface roughness (Ra) measurements of the workpieces were repeated three times in the transverse direction. The average value of the three measurements was then calculated and recorded for each replication.

### Literature Review

Previous studies have extensively utilized the Taguchi method for machining optimization. Yang and Tarn [5] successfully optimized cutting parameters for turning operations using Taguchi's parameter design approach. Research by Nalbant et al. [6] applied the Taguchi method to optimize surface roughness in turning processes. Studies have also highlighted the significant influence of tool geometry, including nose radius, on surface integrity [7, 8]. While optimization studies for various materials and tools are well documented, there remains a need for specific investigations correlating precise nose radii with optimal cutting parameters for aluminum alloys. This work addresses this gap for the 0.4 mm nose radius condition.

### Materials and Experimental Setup

#### Workpiece Material

The workpiece material was an Aluminum–Magnesium alloy (Al–3Mg) round rod ( $\Phi 50$  mm  $\times$  100 mm length). Its chemical composition (major elements: Al 95.56%, Mg 2.95%) and mechanical properties (Tensile Strength: 318 N/mm<sup>2</sup>, Yield Strength: 383 N/mm<sup>2</sup>) are reported in [4].

#### Machine Tool

The experiments were performed on a Samsung PLA25 CNC lathe with a maximum spindle speed of 3500 rpm and a power rating of 20 kW [9].

#### Cutting Tool

A tool holder with a carbide insert having a nose radius ( $r_n$ ) of 0.4 mm was used for turning the Al3Mg samples, as shown in Figures 1 and 2.



Figure 1: Tool geometry.

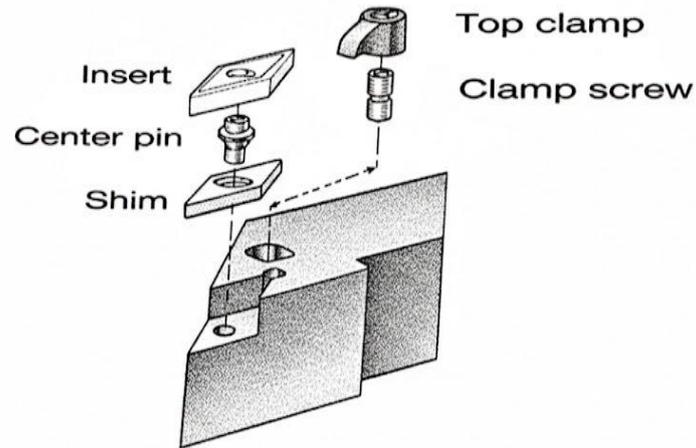


Figure 2: Tool clamping system

#### Measurement Equipment:

Surface roughness (Ra) was measured using a Surtronic 25 stylus-based profilometer, which offers high flexibility and repeatability [10].

MINITAB statistical software was used for designing the experiment (Taguchi Orthogonal Array), calculating S/N ratios, and performing ANOVA [11].

#### Taguchi Experimental Design

##### Selection of Parameters and Levels:

Three control factors were selected, each with three levels, as shown in Table 1.

Table 1 Control Factors and Their Levels.

Factor	Level 1	Level 2	Level 3
A: Feed Rate (mm/rev)	0.3	0.5	0.7
B: Cutting Speed (rpm)	500	700	900
C: Depth of Cut (mm)	0.5	1.0	1.5

##### Orthogonal Array Selection:

For three three-level factors, an L9 ( $3^3$ ) orthogonal array was selected, requiring only 9 experimental runs instead of a full factorial 27 runs [3, 6]. The experimental layout is shown in Table 2 and Figure 3.

Table 2 L9( $3^3$ ) Orthogonal Array and Experimental Results for 0.4 mm Nose Radius.

Exp. No.	A	B	C	Ra1 ( $\mu\text{m}$ )	Ra2 ( $\mu\text{m}$ )	Ra3 ( $\mu\text{m}$ )	Avg. Ra ( $\mu\text{m}$ )
1	1	1	1	14.49	14.54	14.51	14.51
2	1	2	2	11.51	11.49	11.56	11.52
3	1	3	3	10.36	10.37	10.32	10.35
4	2	1	2	22.09	22.05	22.1	22.08
5	2	2	3	18.5	19.2	19	18.90
6	2	3	1	16.75	16.79	16.8	16.78
7	3	1	3	24.07	24.02	24.06	24.05
8	3	2	1	22.82	23.2	23.3	23.11
9	3	3	2	25.93	26.43	26.33	26.23

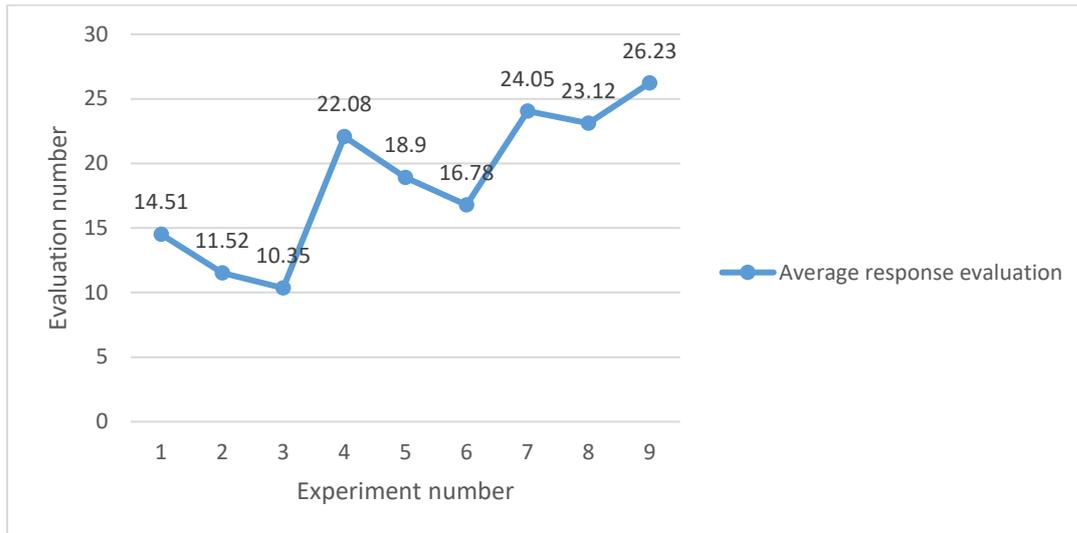


Figure 3 Experimental Results of surface roughness value.

#### Performance Characteristic:

The "smaller-the-better" S/N ratio was chosen to minimize surface roughness. The S/N ratio ( $\eta$ ) is calculated using the formula [6]:

$$\eta = -10 \log_{10} \left( \frac{1}{n} \sum_{i=1}^n y_i^2 \right)$$

where  $y_i$  are the measured surface roughness values and  $n = 3$ .

#### Results and Discussion

##### Analysis of S/N Ratios:

The S/N ratio for each experimental run was calculated. The mean S/N ratio for each factor level was then determined (Table 3). A higher S/N ratio corresponds to better (lower) and more consistent surface roughness.

The optimal level for each factor is the one with the highest mean S/N ratio: A1, B3, C2.

Therefore, the optimal predicted combination is:

Feed Rate = 0.3 mm/rev, Cutting Speed = 900 rpm, Depth of Cut = 1.0 mm.

Table 3 Response Table for Mean S/N Ratios (0.4 mm Nose Radius).

Level	Feed Rate (A)	Cutting Speed (B)	Depth of Cut (C)
1	-21.59	-25.91	-25.00
2	-25.64	-24.68	-25.49
3	-27.76	-24.39	-24.48
Delta	6.17	1.52	1.01
Rank	1	2	3

##### Analysis of Variance (ANOVA):

ANOVA was performed to quantify the influence of each parameter (Table 4).

The results confirm that feed rate (Factor A) is the most statistically significant parameter, contributing 88.97% to the total variation in surface roughness. The F-value for feed rate (25.87) is substantially higher than the critical value, indicating a very strong effect. Cutting speed and depth of cut have relatively minor contributions (4.44% and 3.14%, respectively) within the tested range for this specific tool geometry.

Table 4 ANOVA Results for Surface Roughness (0.4 mm Nose Radius).

Source	DF	Seq SS	Adj MS	F-Value	P (%)
Feed Rate (A)	2	230.244	115.122	25.87	88.97
Cutting Speed (B)	2	11.493	5.747	1.29	4.44
Depth of Cut (C)	2	8.139	4.070	0.91	3.14
Residual Error	2	8.901	4.451		3.45
Total	8	258.777			100

**Prediction and Confirmation:**

The estimated S/N ratio ( $\eta_{\text{calculated}}$ ) and corresponding surface roughness ( $Ra_{\text{calculated}}$ ) under the optimal conditions (A1, B3, C2) were predicted using additive modeling [11]:

$$\eta_{\text{calc}} = \bar{\eta} + (\bar{A}_1 - \bar{\eta}) + (\bar{B}_3 - \bar{\eta}) + (\bar{C}_2 - \bar{\eta}) = -54.121 \text{ dB}$$

$$Ra_{\text{calc}} = 10^{-\eta_{\text{calc}}/20} = 508.21 \mu\text{m}$$

This predicted Ra value represents the expected performance at the optimal parameter setting derived from the model.

**Conclusion**

This study successfully applied the Taguchi method and ANOVA to optimize turning parameters for minimizing the surface roughness of Al<sub>3</sub>Mg alloy using a 0.4 mm nose radius tool.

1. The optimal parameter combination was determined as:
  - Feed Rate = 0.3 mm/rev,
  - Cutting Speed = 900 rpm,
  - and Depth of Cut = 1.0 mm.
2. ANOVA revealed that feed rate is the overwhelmingly dominant factor, accounting for 88.97% of the influence on surface roughness in this configuration. Cutting speed and depth of cut had significantly less impact.
3. The Taguchi method proved to be a highly efficient and systematic tool for machining optimization, enabling the identification of key controlling factors and optimal settings with a minimal number of experiments.

**Recommendations for Future Work**

1. Validate the predicted optimal settings with physical confirmation experiments.
2. Investigate the effects of other tool nose radii (e.g., 0.8 mm, 1.2 mm) on the optimal parameter set and factor dominance, as suggested by the broader study.
3. Study the interaction effects between parameters, which were not considered in this main-effects model.
4. Extend the research to include other performance characteristics like tool wear, cutting forces, and material removal rate.

**References**

1. Thamizhmani, S., Saparudin, S., & Hasan, S. (2007). Analyses of surface roughness by turning process using Taguchi method. *Journal of Achievements in Materials and Manufacturing Engineering*, 20(1–2).
2. Karr, S. F., & Albert, F. (1997). *Technology of machine tools* (5th ed.). McGraw-Hill.
3. Roy, R. K. (2001). *Design of experiments using the Taguchi approach: 16 steps to product and process improvement*. John Wiley & Sons.
4. Chemical and mechanical properties data of Al-3Mg alloy. (2023). *Internal laboratory specification*.
5. Yang, W. H., & Tarn, Y. S. (1998). Design optimization of cutting parameters for turning operations based on the Taguchi method. *Journal of Materials Processing Technology*, 84(1–3), 122–129.
6. Nalbant, M., Gokkaya, H., & Sur, G. (2007). Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. *Materials & Design*, 28(4), 1379–1385.
7. Kishawy, H. A., & Elbestawi, M. A. (1999). Effects of process parameters on material side flow during hard turning. *International Journal of Machine Tools and Manufacture*, 39(7), 1017–1030.
8. Tönshoff, H. K., Arendt, C., & Ben Amor, R. (2000). Cutting of hardened steel. *CIRP Annals*, 49(2), 547–566.
9. Samsung Machine Tools. (2022). *Samsung PLA25 CNC lathe machine technical datasheet*.
10. Taylor Hobson. (2021). *Surtronic 25 surface roughness tester user manual*.
11. Minitab, LLC. (2023). *Minitab statistical software user guide* (Release 19).

**Disclaimer/Publisher's Note:** The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of LOUJAS and/or the editor(s). LOUJAS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.