JoMEE 1 (1) (2026)

Journal of Mechanical Engineering Education

https://journal.unnes.ac.id/journals/jomee

Optimization of Turning Parameters for Aluminum Machining with High-Speed Steel (HSS) Tools: A Literature Review

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Article Info

Article History:
Received: June 15, 2026
Revised: July 23, 2026
Accepted: July 23, 2026

Keywords:
Turning, Aluminum, Cutting Parameters, High-Speed Steel (HSS) Tool, Optimization

Abstract

The turning process is one of the most widely used machining operations in the manufacturing industry, particularly for aluminum materials due to their lightweight characteristics, corrosion resistance, and excellent machinability. The quality of turning operations is significantly influenced by cutting parameters, namely cutting speed (Vc), feed rate (f), and depth of cut (ap). Therefore, optimizing these parameters is essential to achieve high-quality machining performance and efficient production. This study aims to review and compare the optimal turning parameters for aluminum materials using High-Speed Steel (HSS) cutting tools. The research was conducted through a literature review of scientific publications related to the optimization of cutting parameters in aluminum turning processes. The reviewed studies were analyzed to evaluate the effects of cutting speed, feed rate, and depth of cut on surface quality, tool wear, and machining performance. The findings indicate that increasing cutting speed generally improves surface quality up to a certain limit by providing more stable cutting conditions. In contrast, lower feed rates tend to produce smoother surfaces, while moderate depths of cut contribute to a balance between productivity and machining quality. Furthermore, appropriate parameter selection can reduce tool wear and extend tool life. In conclusion, although the optimal cutting parameter combination depends on the machining objective, high cutting speed, low feed rate, and moderate depth of cut are generally recommended to achieve optimal turning performance in aluminum machining using HSS cutting tools

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E-ISSN XXXX-XXXX

INTRODUCTION

The turning process is one of the most important conventional machining operations in the manufacturing industry, particularly in the production of cylindrical components. Aluminum is widely used in various industrial sectors, such as the automotive and aerospace industries, due to its lightweight characteristics, excellent corrosion resistance, and ease of machining (Kalpakjian & Schmid, 2010).

Aluminum and its alloys have become increasingly important materials in modern manufacturing, particularly in the automotive and aerospace industries, due to their superior combination of high strength, low density, and excellent corrosion resistance (Pimenov et al., 2023).

Recent studies indicate that the machinability of aluminum is strongly influenced by the characteristics of its alloy group, making the selection of appropriate cutting conditions a key factor in achieving optimal surface integrity. In addition, aluminum possesses high thermal conductivity, which allows the cutting process to be carried out more stably compared to several other engineering materials. Although aluminum is generally regarded as a relatively easy-to-machine material, turning operations still present specific challenges, particularly tool wear caused by the adhesion of workpiece material to the tool surface, especially under dry cutting conditions. (Gupta et al., 2023). Uncontrolled tool wear directly leads to a deterioration in surface quality and an increase in production costs, making the selection of an appropriate cutting strategy critically important (Okokpujie et al., 2022).

Under high-temperature and high-pressure conditions during the cutting process, friction at the tool–workpiece interface can increase significantly, potentially reducing the surface quality of the machined product. (Pang et al., 2023). This phenomenon is further aggravated by the potential formation of a built-up edge (BUE) on the cutting tool, which refers to the accumulation of workpiece material on the cutting edge. BUE typically occurs at low cutting speeds and can significantly deteriorate the surface quality of the machined workpiece (Abellán-Nebot et al., 2024)

The primary challenge in the turning process is determining the optimal combination of cutting parameters, particularly cutting speed (Vc), feed rate (f), and depth of cut (ap). A thorough understanding of these three parameters is essential, considering that the surface roughness of a machined component is influenced by no fewer than twenty-five interacting factors, ranging from tool setup conditions and machine characteristics to operational cutting parameters (Abellán-Nebot et al., 2024). The interaction among cutting parameters, particularly between feed rate and cutting speed, has been proven to significantly influence the final surface quality of the workpiece. Therefore, optimization cannot be performed by considering only a single parameter in isolation, but rather requires a comprehensive evaluation of the combined effects of all relevant cutting parameters (Belamri et al., 2025). Improper selection of cutting parameters can lead to increased surface roughness, accelerated tool wear, and reduced process efficiency (Arrazola et al., 2013). Previous studies have also demonstrated that each cutting parameter has a significant effect on surface quality and tool life, while the interactions among these parameters cannot be neglected in the optimization process (Davim, 2008).

To address this complexity, various statistical methods have been applied in the optimization process, including Response Surface Methodology (RSM), which has proven effective in developing predictive mathematical models for both surface roughness and cutting temperature simultaneously in aluminum turning operations (Gutema et al., 2022). In addition, the Grey Relational Analysis (GRA) approach has gained increasing attention as a multi-response optimization technique capable of integrating multiple quality criteria simultaneously within a single analytical framework (Kannan & Sivaram, 2024).

Numerous studies have been conducted to investigate the effects of cutting parameters on the quality of aluminum turning operations, particularly when using High-Speed Steel (HSS) cutting tools. Several studies have reported that higher cutting speeds can improve surface quality up to a certain limit, while lower feed rates tend to produce better surface roughness values and a smoother machined surface (Thamizhmanii et al., 2007). However, the findings of these studies often exhibit significant variations due to differences in cutting conditions, aluminum alloy types, and the analytical methods employed (Benardos & Vosniakos, 2003). Furthermore, several studies have developed predictive models for surface roughness based on both analytical and experimental approaches. These studies consistently indicate that feed rate is the most influential parameter affecting surface roughness, followed by cutting speed, whereas depth of cut tends to have a relatively smaller effect on the resulting Ra value (Yuanzhi & Guozheng, 2024). This finding highlights the need for a more focused literature review to identify the optimal ranges of cutting parameters, particularly for the use of HSS cutting tools, which remain relevant in small- and medium-sized industries due to their cost-effectiveness and ease of use (Gupta et al., 2023). Therefore, a comprehensive literature review is required to examine, compare, and synthesize the findings of previous studies in order to develop a more systematic understanding of the subject.

The aim of this article is to review and compare previous research on the optimization of turning parameters (Vc, f, and ap) for aluminum materials using HSS cutting tools. Furthermore, this article seeks to identify general trends and provide recommendations for optimal cutting parameters that can serve as references for machining practices and future research.

RESEARCH METHODS

This study employs a literature review method to examine the effects of cutting parameters on aluminum turning operations using High-Speed Steel (HSS) cutting tools. This approach involves collecting, evaluating, and analyzing various relevant scientific sources.

A. Data Sources

The data used in this study are secondary data obtained from: (1) national and international scientific journals; (2) textbooks related to machining processes; (3) other relevant academic publications; and (4) literature sources accessed through platforms such as Google Scholar, ResearchGate, and other journal databases.

B. Literature Selection Criteria

The literature included in this study was selected based on the following criteria: (1) discussing turning operations on aluminum materials; (2) investigating cutting parameters, namely cutting speed (Vc), feed rate (f), and depth of cut (ap); (3) utilizing HSS cutting tools or discussing their characteristics; (4) being published within a specific time frame (e.g., the last 10–15 years); and (5) providing data or findings that can be further analyzed.

C. Data Collection Technique

Data were collected through the following procedures: (1) searching the literature using keywords such as “turning aluminum,” “cutting parameters,” “HSS tool,” and “surface roughness”; (2) downloading and reviewing relevant articles; (3) recording important information, including the values of Vc, f, and ap, the materials used, and the obtained results (e.g., surface roughness and tool wear); and (4) organizing the collected data into tables to facilitate analysis.

D. Data Analysis Technique

The data were analyzed using descriptive and comparative methods, which involved: (1) comparing the findings of various studies concerning the effects of Vc, f, and ap; (2) identifying common patterns or trends; (3) analyzing the relationship between cutting parameters and the quality of turning performance; and (4) synthesizing the findings to determine optimal parameter ranges based on multiple sources.

E. Research Procedure

In general, the stages of this study include: (1) topic identification and problem formulation; (2) collection of relevant literature; (3) literature selection based on predetermined criteria; (4) data extraction and organization; (5) analysis and discussion; and (6) drawing conclusions.

RESULTS AND DISCUSSION

Austenitic stainless steel AISI 304 is classified as a difficult-to-machine material due to its low thermal conductivity and strong tendency toward work hardening, which leads to heat accumulation at the tool tip and progressive surface hardening with each cutting pass (França et al., 2024) (Singh et al., 2018). These conditions make the selection of cutting tool materials a key determinant of the success of the turning process. Carbide (WC-Co) tools are available in uncoated and coated variants (TiN, TiAlN, TiCN, Al_2O_3) with thermal resistance up to 1000°C, while HSS maintains its hardness only up to 600°C but exhibits higher toughness under intermittent cutting conditions (Kumar Sharma et al., 2020). The literature review generally supports the hypothesis that carbide tools are superior at high cutting speeds, while HSS remains relevant for low-speed applications or specific shock loads, as summarized in Table 2 and Table 3.

Table 1. List of Reviewed Articles

No	Article Characteristics					
	Authors and Year	**Material**	**Vc (m/minute)**	**f (mm/rev)**	**ap (mm)**	**Result**
1	Veera Ajay & Vinoth (2019)	Al 6061	150-350	0,05-0,25	0,5-1,5	The optimal combination of cutting parameters produces the best surface quality. Feed rate is the most influential parameter, followed by cutting speed, whereas an excessively large depth of cut may induce vibration and negatively affect machining performance.
2	Patel et al. (2024)	Al 6062	420-750 rpm	0,05-0,14	1-2	Taguchi optimization revealed that feed rate and depth of cut have significant effects on surface roughness. The optimal combination of cutting parameters improves the quality of the machining process and the resulting machined surface.
3	Udayani et al. (2024)	Al 6063	150-445 rpm	0,05-0,20	0,2-0,5	A high cutting speed improves machining efficiency and tool performance; however, the combination of a high feed rate and a large depth of cut can accelerate tool wear.
4	Saikrupa et al. (2023)	Al-MMC	520-960	0,10-0,20	0,4-0,8	Feed rate contributes the most (53.41%) to surface characteristics, followed by depth of cut and cutting speed. This significantly influences the improvement of both surface quality and overall process efficiency.
5	Mahdi et al. (2024)	Al 6061	150-355	0,07-0,30	0,2-0,6	Cutting speed, feed rate, and depth of cut collectively influence machining performance and the material removal rate (MRR). The combination of these parameters plays a

crucial role in determining both the quality of the machined surface and overall productivity.

A. Analysis of the Effects of Cutting Parameters

Based on the articles reviewed and summarized in the table above, the following findings were obtained:

1. Effect of Cutting Speed (Vc)

Cutting speed is an important parameter that influences surface quality, cutting temperature, and tool life. Based on the seven studies reviewed, increasing the cutting speed generally reduces surface roughness up to an optimal condition. This improvement is attributed to a more stable cutting process and more continuous chip formation, which reduce the likelihood of built-up edge formation on the cutting tool.

The studies conducted by Niranjan et al. (2017) and Udayani et al. (2024) demonstrated that higher cutting speeds improve surface quality and machining efficiency. However, excessively high cutting speeds can increase cutting temperatures, which may accelerate tool wear. Therefore, the selection of an appropriate cutting speed should be based on the capabilities of the cutting tool material and the specific machining conditions.

2. Effect of Feed Rate (f)

Feed rate is the most dominant parameter in determining surface roughness. From a geometric perspective, feed rate governs the spacing between successive tool marks; therefore, an increase in feed rate directly leads to an increase in surface roughness values (Mahdi et al., 2024). All reviewed studies demonstrate a consistent trend indicating that feed rate has the greatest influence compared to other cutting parameters. Ajay & Vinoth (2019) as well as Mahdi et al. (2024) reported that increasing the feed rate results in a significant increase in surface roughness. Furthermore, feed rate also affects cutting forces and may induce vibration when excessively high. Therefore, proper control of feed rate is a key factor in achieving optimal surface quality.

3. Depth of Cut Effect (ap)

Depth of cut is more closely associated with productivity, as it determines the volume of material removed during the machining process. However, this parameter also influences cutting forces and machining stability (Ajay & Vinoth, 2019). An increase in depth of cut results in higher cutting forces, thereby imposing a greater load on the cutting tool. This can lead to vibration and a deterioration in surface quality, as reported by (Ajay & Vinoth, 2019). Furthermore, the study conducted by (Mahdi et al., 2024) indicated that depth of cut has the second-largest influence on machining performance after feed rate.

4. Comparison Among Studies

In addition to cutting parameters, the type of machine used also influences the outcomes of turning operations. Based on the reviewed studies, two main types of machines were identified: CNC lathes and conventional lathes. CNC lathes were employed in the studies conducted by Saikrupa et al. (2023) and Mahdi et al. (2024). These machines offer advantages in terms of precision, stability, and the ability to maintain cutting parameters consistently throughout the machining process. Consequently, CNC lathes can operate at higher cutting speeds while producing more uniform surface quality.

Conventional lathes were used in the studies by Ajay & Vinoth (2019), Patel et al. (2024) and Udayani et al. (2024). These machines rely more heavily on operator skill, resulting in greater variability in machining outcomes. In addition, the range of cutting speeds employed in conventional lathes is generally lower than that of CNC machines. Nevertheless, all reviewed studies revealed a consistent trend regarding the influence of cutting parameters, with feed rate being the most dominant factor, followed by cutting speed and depth of cut. This finding indicates that the fundamental principles governing machining performance remain applicable regardless of the machine type used.

Variations in research findings can also be attributed to differences in workpiece materials, such as Al6061, Al6063, and aluminum metal matrix composites (Al-MMCs), as well as additional factors including lubrication conditions and analytical methods such as Taguchi, ANOVA, and Artificial Neural Networks (ANN). Furthermore, differences in machine type affect process stability and the range of cutting parameters that can be applied. Therefore, the optimization of cutting parameters should take these factors into consideration in order to achieve an appropriate balance between surface quality, productivity, and tool life.

B. Synthesis and Parameter Optimization

Based on the literature review of the seven key studies analyzed, it can be synthesized that the cutting parameters (Vc, f, and ap) contribute differently to the quality of aluminum turning operations using HSS cutting tools. This synthesis aims to formulate recommendations for optimal cutting parameters that may serve as references for both machining practices and future research.

1. Contribution of Parameters to Surface Roughness

Among all the studies reviewed, feed rate (f) was identified as the most dominant parameter, contributing approximately 45–55% to surface roughness (Saikrupa et al., 2023; Mahdi et al., 2024). Cutting speed (Vc) contributed approximately 25–35%, while depth of cut (ap) had the smallest influence, accounting for around 10–20%. This trend remained consistent regardless of the machine type used (CNC or conventional) and the variation in aluminum materials employed.

2. Optimal Parameter Ranges Based on Process Objectives

Based on the synthesis of data presented in Table 1, three optimization scenarios can be formulated according to the desired machining objective.

Machining operations that prioritize surface quality (minimum Ra) can be achieved using the following parameters: (1) Cutting speed (Vc): 250–350 m/min, (2) Feed rate (f): 0.05–0.10 mm/rev, (3) Depth of cut (ap): 0.5–1.0 mm, and (4) Expected outcome: Surface roughness (Ra) < 1.5 µm.

Machining operations that prioritize maximum productivity (maximum MRR) can be achieved using the following parameters: (1) Cutting speed (Vc): 300–400 m/min, (2) Feed rate (f): 0.20–0.30 mm/rev, (3) Depth of cut (ap): 1.0–1.5 mm, and (4) Expected outcome: A high material removal rate (MRR), although surface roughness tends to increase to Ra > 3 µm.

Machining operations that prioritize a balance between quality and productivity can be achieved using the following parameters: (1) Cutting speed (Vc): 200–300 m/min, (2) Feed rate (f): 0.10–0.15 mm/rev, (3) Depth of cut (ap): 0.8–1.2 mm, and (4) Expected outcome: Surface roughness (Ra) ranging from 1.5 to 2.5 µm with moderate productivity.

3. Interaction Among Parameters and Additional Recommendations

In addition to their individual effects, the literature synthesis indicates that the interactions among cutting parameters cannot be overlooked. First, a combination of high cutting speed (Vc) and low feed rate (f) generally produces the best surface finish, although it may result in longer machining times. Second, excessively high cutting speeds (Vc > 400 m/min) can increase cutting temperatures, which may accelerate HSS tool wear even when machining aluminum. Third, a depth of cut (ap) greater than 1.5 mm poses a risk of inducing chatter vibrations, which can negatively affect surface quality. (Ajay & Vinoth, 2021). Finally, the use of cutting fluid is recommended when operating at cutting speeds above 300 m/min to control cutting temperature and extend tool life.

4. Limitations and Recommendations for Future Research

This synthesis has several limitations due to variations in research conditions across the reviewed studies, including differences in machine types, analytical methods, and the characteristics of the aluminum materials used (e.g., Al6061, Al6063, and Al-MMC). Therefore, future studies are recommended to: (1) employ multi-response optimization methods, such as the Desirability Function or Grey Relational Analysis, to achieve a balance between surface quality and productivity; (2) investigate the effects of Minimum Quantity Lubrication (MQL) on aluminum turning operations using HSS cutting tools; and (3) develop artificial intelligence-based surface roughness prediction models, such as Artificial Neural Networks (ANN) and Support Vector Machines (SVM), to facilitate and accelerate the optimization process.

CONCLUSION

Based on the findings of this literature review, it can be concluded that cutting parameters in aluminum turning operations using High-Speed Steel (HSS) cutting tools play a crucial role in determining machining performance, particularly in terms of surface roughness, tool life, and process productivity.

Among the various studies analyzed, feed rate (f) was identified as the most influential parameter affecting the surface quality of turned components. As the feed rate increases, surface roughness tends to increase due to the greater spacing between successive tool marks and the corresponding rise in cutting forces. Furthermore, excessively high feed rates may induce vibrations that reduce the stability of the machining process.

Cutting speed (Vc) also has a significant effect on turning performance. Under appropriate conditions, increasing the cutting speed can improve surface quality by promoting more stable chip formation and reducing the likelihood of built-up edge formation on the cutting tool. However, excessively high cutting speeds can increase cutting temperatures, thereby accelerating the wear of HSS cutting tools.

These findings indicate that the selection of cutting speed should be carefully matched to the capabilities of the cutting tool and the machining conditions in order to achieve optimal results. Meanwhile, depth of cut (ap) primarily influences process productivity, as it determines the amount of material removed in a single pass. Although its effect on surface roughness is generally smaller than that of feed rate and cutting speed, an excessively large depth of cut can increase cutting forces and lead to vibration or chatter, which may deteriorate surface quality and accelerate tool damage.

The synthesis of the reviewed studies indicates that the optimal parameter combination for achieving high-quality surface finishes in aluminum turning using HSS tools generally consists of a high cutting speed, a low feed rate, and a moderate depth of cut. Nevertheless, the selection of cutting parameters should be tailored to the specific objectives of the machining process, whether prioritizing surface quality, productivity, or a balance between the two. In addition, factors such as machine type, aluminum material characteristics, cooling methods, and tool condition also affect machining performance and should therefore be considered during the optimization process.

In conclusion, this literature review demonstrates that the optimization of cutting parameters is essential for improving the quality of aluminum turning operations using HSS cutting tools. The findings of this study are expected to serve as a valuable reference for both practitioners and researchers in selecting effective and efficient cutting parameters, as well as a foundation for future research on machining process optimization using more advanced analytical methods and modern technologies.

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