Effect of Principal Cutting Edge Angle of High-Speed Steel Tools On The Machining Stability of Aluminium 6061 During Turning

Nanang Kosim[1]*, Imran[2], Burhan Hafid[3]

[1,2,3]Department of Mechanical Engineering, Bengkalis State Polytechnic, Bengkalis, Riau, Indonesia
* Corresponding author:
Email: qosimn482@gmail.com

Abstract.
The turning process is one of the most widely used machining operations to produce workpieces with the required dimensions and surface quality. The stability of the turning process is influenced by several machining parameters, one of which is the principal cutting edge angle (κr) of the cutting tool. Variations in the principal cutting edge angle affect the distribution of cutting forces, vibration characteristics, and machining stability. This study aims to analyze the effect of principal cutting edge angle variations of High-Speed Steel (HSS) cutting tools on the stability of the turning process of Aluminium 6061. The experiment was conducted using a conventional lathe with three principal cutting edge angle variations, namely 45°, 60°, and 90°. Other machining parameters, including spindle speed, feed rate, depth of cut, workpiece material, and cutting tool material, were maintained constant throughout the experiment. Machining stability was evaluated based on vibration measurements using a vibration meter, and each experimental condition was repeated three times. The experimental data were analyzed using One-Way Analysis of Variance (ANOVA). The results indicated that the average vibration values for κr angles of 45°, 60°, and 90° were 0.933 mm/s, 0.740 mm/s, and 0.743 mm/s, respectively. Statistical analysis showed a significant effect of principal cutting edge angle variation on vibration level ($F = 50.82$, $p < 0.05$). Among the tested angles, the 60° principal cutting edge angle produced the lowest vibration level, indicating the highest turning process stability. These findings demonstrate that selecting an appropriate principal cutting edge angle can improve machining stability and optimize turning performance for Aluminium 6061.
Keywords: *Turning process; Principal cutting edge angle; High-Speed Steel; Aluminium 6061; Vibration and Machining stability.*

I. INTRODUCTION

Turning is one of the most widely employed machining operations in manufacturing industries because of its ability to produce cylindrical components with high dimensional accuracy, excellent surface finish, and high production efficiency. The process is extensively utilized in the aerospace, automotive, marine, and general engineering industries, where precision, product quality, and manufacturing consistency are essential requirements. In a turning operation, material is removed from a rotating workpiece by a single-point cutting tool through a continuous cutting action. The performance of this process is determined not only by the dimensional accuracy of the machined component but also by the stability of the machining system throughout the cutting operation. Therefore, achieving a stable machining process has become one of the primary objectives in modern manufacturing because it directly influences machining quality, tool life, production efficiency, and manufacturing cost (Groover, 2020; Kalpakjian & Schmid, 2014).

Machining stability refers to the ability of a machining system to maintain consistent cutting conditions without experiencing excessive dynamic disturbances during material removal. A stable turning process produces relatively constant cutting forces, uniform chip formation, predictable tool wear, and satisfactory surface integrity. Conversely, unstable cutting conditions generate fluctuating cutting forces that reduce machining accuracy and increase the possibility of vibration. According to Altintas (2012), machining stability is governed by the dynamic interaction among the machine tool, cutting tool, workpiece, and cutting forces generated during chip formation. Disturbances occurring in any part of this machining system may reduce process stability and deteriorate machining performance.

Among the various factors affecting machining stability, vibration is considered one of the most critical phenomena encountered during turning operations. Vibration occurs because the cutting tool and the rotating workpiece continuously interact under dynamic loading conditions. This interaction causes variations in chip thickness and cutting force, which may subsequently induce oscillatory motion within the machining system. Excessive vibration reduces machining performance by increasing surface roughness, decreasing dimensional accuracy, accelerating tool wear, and shortening machine tool life. In severe conditions, vibration may develop into regenerative chatter, a self-excited vibration that significantly degrades machining quality and process reliability (Zheng et al., 2021; Harris & Piersol, 2010).

From the manufacturing perspective, vibration is not merely a dynamic phenomenon but also an important indicator of machining stability. Lower vibration levels generally indicate that the cutting process is operating under stable conditions, whereas higher vibration amplitudes reflect unstable cutting behaviour resulting from fluctuating cutting forces and elastic deformation within the machining system. Consequently, vibration measurement has become one of the most widely accepted approaches for evaluating machining stability because it directly represents the dynamic response of the cutting system during material removal. In addition, vibration analysis enables researchers to evaluate the influence of machining variables objectively without relying solely on surface roughness or dimensional inspection (Zheng et al., 2021).

Numerous variables influence vibration generation during turning operations, including machine rigidity, spindle characteristics, workpiece clamping conditions, cutting parameters, workpiece material, cutting tool material, and cutting tool geometry. Among these variables, cutting tool geometry has received considerable attention because it directly determines chip formation, cutting force distribution, heat generation, and the interaction between the cutting edge and the workpiece. The geometric characteristics of a cutting tool govern how the cutting load is distributed during machining, thereby affecting the dynamic behaviour of the entire machining system (Boothroyd & Knight, 2006; Rochim, 2007).

One of the most influential geometric parameters is the principal cutting edge angle (κr). This angle is defined as the angle formed between the major cutting edge of the tool and the feed direction within the reference plane of the cutting tool geometry. Variations in the principal cutting edge angle modify the effective contact length between the cutting edge and the workpiece, resulting in different distributions of tangential, radial, and axial cutting forces. Since these force components determine the elastic deformation of both the cutting tool and the workpiece, changing the principal cutting edge angle inevitably affects machining stability. According to the theoretical framework presented in this study, the principal cutting edge angle plays an important role in controlling cutting force distribution and vibration behaviour during turning operations.

The influence of the principal cutting edge angle becomes particularly significant because the radial cutting force component contributes directly to tool deflection and workpiece deformation. When excessive radial force is generated, elastic displacement occurs within the machining system, causing fluctuations in chip thickness and cutting force. These fluctuations subsequently increase vibration intensity and reduce machining stability. In contrast, a more favourable principal cutting edge angle can distribute cutting forces more uniformly along the cutting edge, reducing radial loading and improving process stability. The theoretical discussion in this research indicates that smaller κr values generally produce a longer contact length and a more evenly distributed cutting load, whereas larger κr values tend to increase radial force, making the machining system more susceptible to vibration under identical machining conditions.

Besides tool geometry, workpiece material also plays a significant role in determining machining performance. Aluminium 6061 is one of the most widely used heat-treatable aluminium alloys because of its excellent machinability, high corrosion resistance, low density, and favourable mechanical properties. These characteristics make Aluminium 6061 suitable for various engineering applications, including aerospace structures, automotive components, marine equipment, bicycle frames, and precision mechanical products. Owing to its relatively low cutting resistance, Aluminium 6061 can be machined at relatively high cutting speeds while maintaining satisfactory surface quality. Nevertheless, inappropriate machining conditions may still generate excessive vibration, leading to unstable cutting behaviour and reduced machining quality.

In conventional turning operations, High-Speed Steel (HSS) remains one of the most commonly used cutting tool materials because it offers a balanced combination of wear resistance, toughness, ease of regrinding, and economical production cost. Compared with more advanced cutting tool materials, HSS is particularly suitable for conventional machine tools operating under moderate cutting conditions. Furthermore, its mechanical characteristics make it an appropriate material for investigating the influence of cutting tool geometry because the effects of geometric modification can be observed without introducing excessive complexity arising from advanced coating technologies or ultra-high-speed machining conditions.

II. MATERIALS AND METHODS

2.1 Materials and Cutting Tools –

describes the workpiece material, cutting tool material, and the machining parameters employed throughout the experiments. The turning experiments were conducted under constant machining conditions to investigate the effect of the principal cutting edge angle (κr) on machining stability.

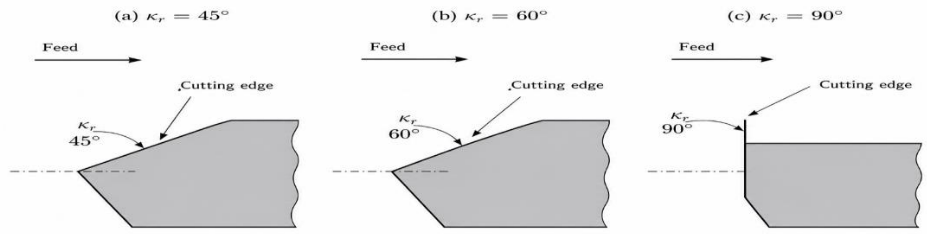

Figure 4. Geometry of HSS cutting tools with principal cutting edge angles (κ_r) of 45°, 60°, and 90°.

The machining parameters used throughout the experiments are summarized in Table 1.

Table 1. Machining parameters and experimental conditions.

Parameter	Specification
Workpiece material	Aluminium 6061
Cutting tool material	High-Speed Steel (HSS)
Principal cutting edge angle, κr	45°, 60°, and 90°
Cutting speed	90 m/min
Spindle speed	755 rpm
Feed rate	0.10 mm/rev
Depth of cut	1.0 mm
Cutting condition	Dry cutting
Response variable	Vibration (mm/s)
Number of repetitions	Three repetitions for each cutting edge angle
Statistical analysis	One-Way Analysis of Variance (ANOVA)

2.2 Experimental Setup –

presents the conventional lathe machine, measuring instruments, workpiece mounting configuration, and The overall experimental procedure is presented in Figure 2.

Fig. 1. Experimental setup for turning and vibration measurement

Figure 1 illustrates the experimental setup employed in this study. Aluminium 6061 was mounted on the spindle using a three-jaw chuck and machined on a conventional lathe with a single-point High-Speed Steel (HSS) cutting tool. Three principal cutting edge angles (κr = 45°, 60°, and 90°) were investigated while all other machining parameters were kept constant. During the turning process, vibration was measured using a vibration meter to evaluate the machining stability under different cutting edge angles.

2.3 Experimental Procedure –

explains the experimental workflow, including specimen preparation, cutting tool installation, machining procedures, and the implementation of the three principal cutting edge angle (κr) variations.

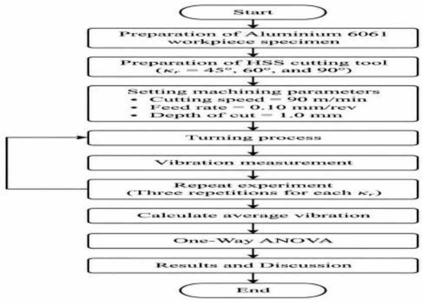

Figure 2. Flowchart of the experimental procedure.

2.4 Vibration Measurement –

Machining vibration was measured during each turning experiment to evaluate the effect of the principal cutting edge angle (κr) on machining stability. The vibration data were recorded under identical cutting conditions for all experimental trials to ensure consistency and reliability. Each cutting edge angle (45°, 60°, and 90°) was tested three times, and the measured vibration values were expressed in millimeters per second (mm/s). The average vibration value obtained from the three repetitions was used as the representative response for subsequent analysis and comparison among the different cutting tool geometries.

2.5 Statistical Analysis –

The experimental data were analyzed using One-Way Analysis of Variance (ANOVA) to determine whether the principal cutting edge angle had a statistically significant effect on machining vibration. The analysis was performed by comparing the average vibration values obtained for the three cutting edge angles (45°, 60°, and 90°). A significance level of $\alpha = 0.05$ was adopted for hypothesis testing. Differences were considered statistically significant when the p-value was less than 0.05, indicating that variations in the principal cutting edge angle significantly influenced the vibration generated during the turning process.

3.1 EFFECT OF PRINCIPAL CUTTING EDGE ANGLE (KR) ON MACHINING VIBRATION

The vibration measurements obtained during the turning of Aluminium 6061 demonstrated that variations in the principal cutting edge angle (κr) significantly affected the dynamic behaviour of the machining process. Under constant machining parameters, including a cutting speed of 90 m/min, spindle speed of 755 rpm, feed rate of 0.1 mm/rev, depth of cut of 1 mm, and dry cutting conditions, different κr values produced distinct vibration responses. These results indicate that modifying the cutting tool geometry alone can alter the stability of the turning operation.

Table 2. Experimental vibration results

Principal cutting edge angle, κr (°)	**Trial 1 (mm/s)**	**Trial 2 (mm/s)**	**Trial 3 (mm/s)**	**Average (mm/s)**
45	0.93	0.94	0.93	**0.933**
60	0.74	0.74	0.74	**0.740**
90	0.74	0.75	0.74	**0.743**

As shown in Table 2, the highest average vibration was recorded at a principal cutting edge angle of 45° with an average value of 0.933 mm/s. In contrast, the lowest average vibration was obtained at 60° (0.740 mm/s), while the vibration measured at 90° was slightly higher (0.743 mm/s). These findings indicate that a principal cutting edge angle of 60° provided the most stable machining condition under the selected cutting parameters.

The experimental results showed that the average vibration level at a principal cutting edge angle of 45° was 0.933 mm/s, which was the highest among all experimental conditions. When the principal cutting edge angle was increased to 60°, the average vibration decreased to 0.740 mm/s, representing the lowest vibration level recorded during the experiments. A further increase in the principal cutting edge angle to 90° resulted in an average vibration of 0.743 mm/s. Although this value remained considerably lower than that obtained at 45°, it was slightly higher than the vibration measured at 60°. These findings indicate that the turning process achieved its highest stability when the cutting tool was configured with a principal cutting edge angle of 60°.

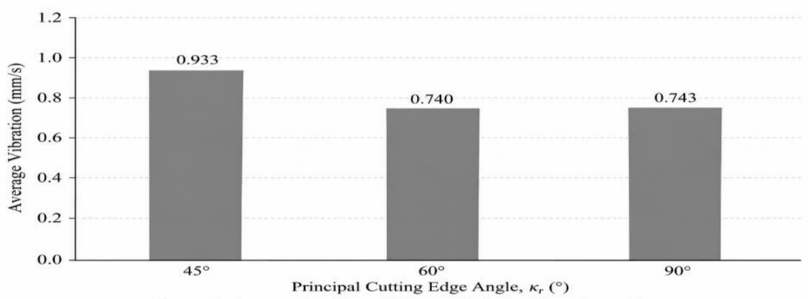

Figure 3. Average vibration at different principal cutting edge angles.

The observed reduction in vibration at κr = 60° suggests that this cutting geometry provided a more favourable distribution of cutting forces during material removal. Since all machining parameters were maintained constant throughout the experiments, the variation in vibration response can reasonably be attributed to the change in the principal cutting edge angle. This finding confirms that cutting tool geometry plays a significant role in determining the dynamic performance of the machining system.

Conversely, the highest vibration recorded at κr = 45° indicates that this cutting geometry generated a less stable cutting condition. Higher vibration levels generally reflect larger fluctuations in cutting forces acting on the tool–workpiece system, leading to increased dynamic excitation during machining. Although the average vibration measured at κr = 90° was substantially lower than that at 45°, the slight increase relative to κr = 60° indicates that increasing the principal cutting edge angle beyond the intermediate value did not further improve machining stability under the selected cutting conditions.

Overall, the experimental results demonstrate a clear relationship between the principal cutting edge angle and machining vibration. Among the three cutting tool geometries investigated, the 60° principal cutting edge angle produced the lowest average vibration, indicating the most stable machining condition for turning Aluminium 6061 with a High-Speed Steel cutting tool under the machining parameters employed in this study. The vibration trend obtained from the experiments provides the initial evidence that the principal cutting edge angle influences machining stability and forms the basis for the subsequent statistical analysis presented in the following section.

3.2 STATISTICAL ANALYSIS

To evaluate the statistical significance of the principal cutting edge angle (κr) on machining vibration, the experimental data were analyzed using a one-way Analysis of Variance (ANOVA). The analysis was performed on the average vibration values obtained from the three principal cutting edge angle variations (45°, 60°, and 90°), with each experimental condition repeated three times to improve data reliability.

Table 3. One-Way ANOVA results for machining vibration

Source of Variation	Sum of Squares (SS)	df	Mean Square (MS)	F-value	p-value
Between Groups	0.07337	2	0.03669	50.82	0.00017
Within Groups	0.00434	6	0.00072	–	–
Total	0.07771	8	–	–	–

The ANOVA results revealed a calculated F-value (F = 50.82), which exceeded the critical F-value (F_{critical} = 5.14) at a significance level of α = 0.05. Furthermore, the obtained p-value was 0.00017, which was substantially lower than the predetermined significance level ($p < 0.05$). These statistical results indicate that the variation in the principal cutting edge angle significantly affected the vibration response during the turning of Aluminium 6061.

The statistical findings confirm that the observed differences in vibration among the three cutting tool geometries were not caused by random experimental variation. Instead, they demonstrate that modifying the principal cutting edge angle produced a measurable change in the dynamic behaviour of the machining system. Consequently, the null hypothesis (H_0), stating that variations in the principal cutting edge angle have no significant effect on machining vibration, was rejected, while the alternative hypothesis (H_1) was accepted.

The significance identified by the ANOVA analysis supports the experimental observations presented in the previous section, where the 60° principal cutting edge angle consistently produced the lowest average vibration level. This agreement between the experimental measurements and statistical analysis strengthens the reliability of the findings and confirms that the principal cutting edge angle is an influential machining parameter affecting process stability under the selected cutting conditions.

Overall, the statistical analysis verifies that the selection of an appropriate principal cutting edge angle contributes significantly to improving machining stability. Within the range of cutting tool geometries investigated in this study, the 60° principal cutting edge angle provided the most stable turning condition for Aluminium 6061, as evidenced by both the lowest measured vibration level and the statistically significant differences identified through one-way ANOVA.

III. DISCUSSION

The experimental results demonstrate that the principal cutting edge angle (κr) has a significant influence on the dynamic stability of the turning process. Among the three cutting tool geometries investigated, the 60° principal cutting edge angle produced the lowest average vibration (0.740 mm/s), whereas the 45° cutting edge angle generated the highest vibration (0.933 mm/s). Although the vibration level obtained at κr = 90° (0.743 mm/s) was comparable to that of κr = 60°, it remained slightly higher, indicating that the intermediate cutting edge angle provided the most stable machining condition under the selected cutting parameters.

The influence of the principal cutting edge angle can be explained through the mechanics of metal cutting. During turning, the cutting edge angle governs the direction and magnitude of the cutting force components acting on the tool and workpiece. Variations in κr modify the distribution of tangential, radial, and axial forces, thereby influencing elastic deformation and the dynamic response of the machining system. As explained by Boothroyd and Knight (2006) and Kalpakjian and Schmid (2014), an appropriate cutting tool geometry promotes a more balanced force distribution, reducing excessive radial loading that may cause tool deflection and vibration. Consequently, machining stability depends not only on the selected cutting parameters but also on the ability of the cutting tool geometry to distribute cutting forces efficiently.

The superior performance observed at κr = 60° suggests that this geometry provided a more favourable balance between the cutting force components. Under constant spindle speed, feed rate, and depth of cut, the intermediate cutting edge angle likely reduced excessive radial loading while maintaining efficient chip formation. This balanced force distribution minimized dynamic excitation within the machine–tool–workpiece system, resulting in lower vibration levels and improved machining stability. Conversely, the higher vibration observed at κr = 45° indicates that the cutting process experienced larger force fluctuations, which increased the dynamic response of the machining system during material removal.

These findings are consistent with the theory of machining dynamics presented by Altintas (2012), who emphasized that machining stability is governed by the interaction between cutting forces and the structural dynamics of the machine tool system. Fluctuating cutting forces produce elastic deformation of the tool and workpiece, increasing the possibility of self-excited vibration and reducing process stability. Similarly, Zheng et al. (2021) explained that vibration is one of the primary indicators of machining stability because it directly reflects the dynamic behaviour of the cutting system. Therefore, the reduction in vibration measured at κr = 60° indicates that this cutting geometry provided a more stable machining condition than the other investigated configurations.

The present findings also agree with previous studies investigating the influence of cutting tool geometry on machining performance. Aminy and Aji (2022) reported that variations in the principal cutting edge angle of High-Speed Steel tools affected the machining quality of Aluminium 6061. Although their study evaluated surface roughness rather than machining vibration, both investigations demonstrate that modifying the principal cutting edge angle significantly influences machining performance. Likewise, Deny Ahmad Praptias and Sunyoto (2020) showed that cutting tool angle, together with cutting parameters, contributes to variations in machining quality. Furthermore, Suwanda et al. (2024) concluded that the cutting angle plays an important role in determining the machining characteristics of Aluminium 6061. Despite differences in the response variables investigated, the overall trend observed in these studies is consistent with the present research, confirming that cutting tool geometry is a critical factor affecting machining performance.

An important contribution of this study lies in the use of vibration as the primary indicator of machining stability. While many previous investigations focused on surface roughness, tool wear, or cutting force, this research evaluated the dynamic response of the machining system directly through vibration measurements. This approach provides additional insight into the influence of the principal cutting edge angle on machining stability and complements previous studies on Aluminium 6061 turning using High-Speed Steel cutting tools.

Overall, the experimental observations, supported by statistical analysis and theoretical interpretation, confirm that the principal cutting edge angle significantly affects machining stability during the turning of Aluminium 6061. Among the investigated cutting tool geometries, the 60° principal cutting edge angle provided the most favourable machining condition by producing the lowest vibration level under constant machining parameters. These findings demonstrate that appropriate selection of cutting tool geometry can improve machining stability and may serve as a practical reference for optimizing conventional turning operations involving Aluminium 6061.

The experimental results indicate that the principal cutting edge angle (κr) has a significant influence on machining vibration during the turning of Aluminium 6061. As presented in Table 2 and Figure 3, the HSS cutting tool with a principal cutting edge angle of 60° produced the lowest average vibration (0.740 mm/s), whereas the 45° cutting edge angle generated the highest average vibration (0.933 mm/s). The vibration measured at 90° (0.743 mm/s) was only slightly higher than that at 60°, indicating that both geometries provided more stable cutting conditions than the 45° tool.

The higher vibration observed at a principal cutting edge angle of 45° can be explained by the distribution of cutting forces acting on the cutting tool. A smaller principal cutting edge angle increases the engagement length between the cutting edge and the workpiece, resulting in a larger radial force component. This radial force tends to deflect the cutting tool and workpiece, thereby increasing the dynamic response of the machining system and leading to higher vibration levels. Increased vibration may also reduce machining stability, accelerate tool wear, and negatively affect the surface quality of the machined component.

Conversely, the cutting tool with a principal cutting edge angle of 60° exhibited the lowest vibration because the cutting forces were distributed more uniformly between the tangential and radial directions. This balanced force distribution reduced tool deflection and improved the dynamic stability of the cutting process. Consequently, the tool maintained a more stable engagement with the workpiece, resulting in lower vibration under the selected machining conditions.

Although the average vibration obtained at a principal cutting edge angle of 90° was very close to that of 60°, the slightly higher value suggests that a larger cutting edge angle alters the direction of the cutting forces, concentrating a greater portion of the load in the feed direction. Under the machining conditions employed in this study, this change in force direction did not produce vibration levels as low as those achieved with the 60° cutting edge angle.

The ANOVA results presented in Table 3 further confirm these observations. The calculated F-value of 50.82 and the corresponding p-value of 0.00017 indicate that the differences in vibration among the three principal cutting edge angles are statistically significant ($p < 0.05$). Therefore, the null hypothesis was rejected, confirming that the principal cutting edge angle significantly affects machining vibration during the turning of Aluminium 6061.

These findings are consistent with previous studies reporting that cutting tool geometry plays a critical role in determining machining stability by influencing the magnitude and direction of cutting forces. The present study extends this understanding by demonstrating that, under identical machining parameters and using an HSS cutting tool, a principal cutting edge angle of 60° provides the most stable cutting condition for turning Aluminium 6061. This finding offers practical guidance for selecting cutting tool geometry to minimize machining vibration, improve process stability, and potentially enhance machined surface quality and tool life.

IV. CONCLUSIONS

This study investigated the influence of the principal cutting edge angle (κr) on the machining stability of Aluminium 6061 during conventional turning using High-Speed Steel (HSS) cutting tools. Three principal cutting edge angle variations, namely 45°, 60°, and 90°, were evaluated under identical machining conditions to isolate the effect of tool geometry on the vibration response of the machining system.

The experimental results demonstrated that the principal cutting edge angle significantly affected machining vibration. The lowest average vibration level was obtained at κr = 60° (0.740 mm/s), indicating the most stable machining condition among the investigated cutting tool geometries. In contrast, κr = 45° produced the highest average vibration (0.933 mm/s), while κr = 90° resulted in a slightly higher vibration level (0.743 mm/s) than that observed at κr = 60°. These findings indicate that an appropriate selection of the principal cutting edge angle contributes to improved machining stability by reducing vibration during the turning process.

The statistical analysis further confirmed the experimental observations. The one-way ANOVA results showed a calculated F-value of 50.82, which exceeded the critical F-value (5.14), with a p-value of 0.00017 (< 0.05). These results demonstrate that the variation in the principal cutting edge angle has a statistically significant effect on machining vibration, confirming that cutting tool geometry is an important factor Influencing the dynamic behaviour of the machining process.

Overall, this study demonstrates that the use of a 60° principal cutting edge angle provides the most favourable machining stability for turning Aluminium 6061 under the selected cutting conditions. The findings contribute to a better understanding of the relationship between cutting tool geometry and machining vibration and may serve as a practical reference for selecting appropriate cutting tool geometry in conventional turning operations. Future studies are recommended to investigate the combined effects of the principal cutting edge angle with other machining parameters, such as cutting speed, feed rate, and depth of cut, as well as different workpiece and cutting tool materials to establish a more comprehensive understanding of machining stability. This study investigated the effect of the principal cutting edge angle (κr) of High-Speed Steel (HSS) cutting tools on machining vibration during the turning of Aluminium 6061 under constant machining parameters. The experimental results demonstrated that the principal cutting edge angle significantly influenced machining vibration. Among the three cutting edge angles evaluated, κr = 60° produced the lowest average vibration value of 0.740 mm/s, indicating the most stable cutting condition. In contrast, κr = 45° generated the highest vibration level, while κr = 90° produced a slightly higher vibration than κr = 60°.

The statistical analysis using One-Way ANOVA confirmed that the observed differences in vibration were statistically significant ($F = 50.82$, $p = 0.00017 < 0.05$), indicating that the principal cutting edge angle has a significant effect on machining vibration during the turning of Aluminium 6061. These findings demonstrate that selecting an appropriate cutting tool geometry is an important factor in improving machining stability.

From a practical perspective, the results of this study provide useful guidance for selecting the principal cutting edge angle of HSS cutting tools to minimize machining vibration during turning operations. Improved machining stability may contribute to better surface quality, reduced tool wear, and enhanced dimensional accuracy of machined components. Future studies are recommended to investigate the influence of the principal cutting edge angle under different cutting speeds, feed rates, depths of cut, workpiece materials, and cutting tool materials to further optimize machining performance and broaden the applicability of the findings.

From a practical perspective, the findings of this study provide useful guidance for selecting the appropriate principal cutting edge angle of High-Speed Steel (HSS) cutting tools to minimize machining vibration during the turning of Aluminium 6061. Improved machining stability may contribute to better surface quality, reduced tool wear, and enhanced dimensional accuracy. Future research is recommended to investigate the influence of the principal cutting edge angle under different cutting speeds, feed rates, depths of cut, workpiece materials, and cutting tool materials to further optimize machining performance and broaden the applicability of the present findings.

REFERENCES

[1] of cut, workpiece materials, and cutting tool materials to further optimize machining performance and broaden the applicability of the present findings.

[2] Zheng, L., Chen, W., & Huo, D. (2021). Vibration Assisted Machining: Theory, Modelling and Applications. Wiley-ASME Press.

[3] Aminy, A. Y., & Aji, A. A. (2022). Optimization of the Turning Quality of Aluminum 6061 Due to Changes in HSS Cutting Tool Angle. ***Journal of Mechanical Engineering.***

[4] Deny Ahmad Praptias, & Sunyoto. (2020). The Effect of Depth of Cut, Cutting Speed, and HSS Tool Angle on Surface Roughness in the Turning Process. ***Journal of Mechanical Engineering.***

[5] Lilingan, G. R. (2023). Quality Characteristics of Orthogonal Turning of Aluminum 6061 at High Cutting Speeds. Undergraduate Thesis, Mechanical Engineering Study Program.

[6] Suwanda, T., Budiyantoro, et al. (2024). The Effect of Cutting Depth, Feed Rate, and Cutting Angle on Surface Roughness in the Lathe Process of Aluminum 6061**.** ***International Journal of Mechanical Engineering***.

[7] Syinta, & Revaldy Dwi. (2025). Analysis of the Effect of Tool Angle and Depth of Cut Variations on Aluminum 6061 Using Conventional Turning Process. Undergraduate Thesis, Department of Mechanical Engineering.

[8] Thoifur, M. (2024). The Effect of Feed Rate and Depth of Cut Variations on Surface Roughness in CNC Turning of Aluminum 6061 Using a Leadwell LTC-200 Machine. Undergraduate Thesis, Department of Mechanical Engineering.

[9] Boothroyd, G., & Knight, W. A. (2006). Fundamentals of Machining and Machine Tools (3rd ed.). CRC Press.

[10] Groover, M. P. (2020). Fundamentals of Modern Manufacturing: Materials, Processes, and Systems (7th ed.). John Wiley & Sons.

[11] Kalpakjian, S., & Schmid, S. R. (2014). Manufacturing Engineering and Technology (7th ed.). Pearson.

[12] Trent, E. M., & Wright, P. K. (2000). Metal Cutting (4th ed.). Butterworth-Heinemann.

[13] Rao, P. N. (2018). Manufacturing Technology: Metal Cutting and Machine Tools. McGraw-Hill Education.

[14] Altintas, Y. (2012). Manufacturing Automation: Metal Cutting Mechanics, Machine Tool Vibrations, and CNC Design (2nd ed.). Cambridge University Press.

[15] Stephenson, D. A., & Agapiou, J. S. (2016). Metal Cutting Theory and Practice (3rd ed.). CRC Press.

[16] Youssef, H. A., & El-Hofy, H. A. (2008). Machining Technology: Machine Tools and Operations. CRC Press.

[17] Childs, T. H. C. (2000). Metal Machining: Theory and Applications. Butterworth-Heinemann.

[18] Harris, C. M., & Piersol, A. G. (2010). Harris' Shock and Vibration Handbook (6th ed.). McGraw-Hill.

[19] Smith, G. T. (2008). Cutting Tool Technology: Industrial Handbook. Springer.

[20] Davim, J. P. (Ed.). (2010). Machining: Fundamentals and Recent Advances. Springer.

[21] Widarto. (2008). Machining Techniques. Directorate of Vocational High School Development.

[22] Rochim, T. (2007). Theory and Technology of Machining Processes. Bandung Institute of Technology.

[23] Montgomery, D. C. (2019). Design and Analysis of Experiments (10th ed.). John Wiley & Sons.

[24] Walpole, R. E., Myers, R. H., Myers, S. L., & Ye, K. (2017). Probability and Statistics for Engineers and Scientists (9th ed.). Pearson.

[25] Gaspersz, V. (1991). Experimental Design Methods. Armico.

[26] Sugiyono. (2022). Quantitative, Qualitative, and R&D Research Methods. Alfabeta.

[27] Sudjana. (2005). Statistical Methods. Tarsito.