

The Correlation of Tool Wear, Tool Failure and Diameter Cylindricity on Drilling Application of Aircraft Component

Aishah Ahmad¹, Rasidi Ibrahim^{1*}, Fadhil Supaat¹, Kamaruddin Kamdani¹,
Chong Bin Hong², Artem Marchenkov³

¹ Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia (UTHM), Johor, MALAYSIA

² HPMT Industries Sdn Bhd, Jalan Sungai Kayu Ara 32/39,
Taman Perindustrian Berjaya, 40460 Shah Alam, Selangor, MALAYSIA

³ Department of Metals Technologies,
Moscow Power Engineering Institute (MPEI), 111250, Moscow, RUSSIA

*Corresponding Author: rasidi@uthm.edu.my

DOI: <https://doi.org/10.30880/ijie.2025.17.08.005>

Article Info

Received: 1 June 2025

Accepted: 20 November 2025

Available online: 31 December 2025

Keywords

Tool wear, cylindricity, Al6061,
carbide drill bit, feedrate, cutting
speed, ISO

Abstract

In aircraft manufacturing, precision drilling is essential for ensuring the structural integrity of aircraft components, particularly when working with aluminum alloys like Al6061. A key challenge arises from tool wear, which compromises the accuracy of cylindrical hole dimensions. This study investigates the relationship between drill bit wear and the resulting hole dimensions under varying feed rates. Using six different feed rates, experiments were conducted on Al6061 plates to assess the impact of tool wear on hole cylindricity. The findings reveal a direct correlation between increased tool wear and larger cylindrical hole diameters. Among the tested feed rates, 0.26 mm/rev demonstrated optimal performance, showing consistent patterns in which drill bit wear was minimized, resulting in improved precision compared to higher or lower feed rates. These results highlight the importance of selecting appropriate feed rates to maintain drilling accuracy and reduce tool wear. In the present study, a feed rate of 0.260 mm/rev provided the best drilling performance, particularly with Drills 3 and 6. However, inconsistencies were noted with Drill 5 at a feed rate of 0.33 mm/rev, which could be attributed to residual Build Up Edges (BUE) making the assessment of tool wear more complex. In conclusion, this finding provides valuable insights into improving precision in drilling operations, ultimately contributing to more reliable and durable aircraft structures.

1. Introduction

This study investigates the relationships between tool wear, tool failures, and the precision of drilled holes in aviation components. Precision drilling is critical in aircraft production, but it wears out the tools, making maintenance difficult and shortening tool life [1]. This has an impact on the overall quality of airplane parts, including weight distribution, material stress, and aerodynamic efficiency. The study focuses on drilling into aluminum alloy (Al6061), a commonly used material in aircraft manufacturing, and seeks to understand how tool wear and failure affect the quality of drilled holes. Drilling in airplane components is difficult due to the strict hole quality requirements by the aircraft industry [2]. The study's goal is to see how tool wear and failure affect the precision of drilled holes. Specific objectives include investigating tool wear during drilling, assessing tool life in

This is an open access article under the CC BY-NC-SA 4.0 license.



accordance with industry standards, and exploring how tool wear and failure are related to the cylindrical shape of the holes. This research aims to provide insights that can help the manufacturing industry better understand and control these aspects during the drilling process.

The key challenges in drilling processes primarily center on tool wear, tool failure, and the cylindricity of the drilled diameter. This study investigates the performance of a specific drilling tool on an aluminum alloy, considering various parameters such as feed rate and cutting speed. The primary objective is to assess the influence of these factors on tool performance and to determine how closely the resulting hole geometry aligns with industry standards. Given the limited existing data on the relationship between tool degradation and hole precision in drilling applications for aviation components, this research is crucial. Ultimately, the study aims to offer valuable insights that can contribute to improving the quality and precision of aircraft components in manufacturing.

2. Machine, Tools and Materials

The following experiment was carried out using six 20 mm-thick aluminum alloy (Al6061) plates along with six carbide drill bits whose diameters ranged from 9.8 mm to 12.7 mm as depicted in Figure 1. Despite the widespread use of aluminum alloys in aviation applications, including structural components, exterior surfaces, and interior skins, Al6061 was selected due to its wide application in aerospace [3]. The choice was made to use carbide drill bits due to their superior temperature resistance, which is particularly useful when it comes to machining aluminum, especially at high cutting rates when a great deal of heat is generated during the process. The thermal resistance of carbide drill bits is higher than that of high-speed steel bits, thus reducing the risk of thermal damage during the machining process as compared with high-speed steel bits [4]. Furthermore, carbide drill bits exhibit chemical resistance, which helps to prevent adhesion and the formation of a built-up edge associated with aluminum, such as a built-up edge that can occur as a result of the ductility of the metal, thereby extending the life of the tool [5].

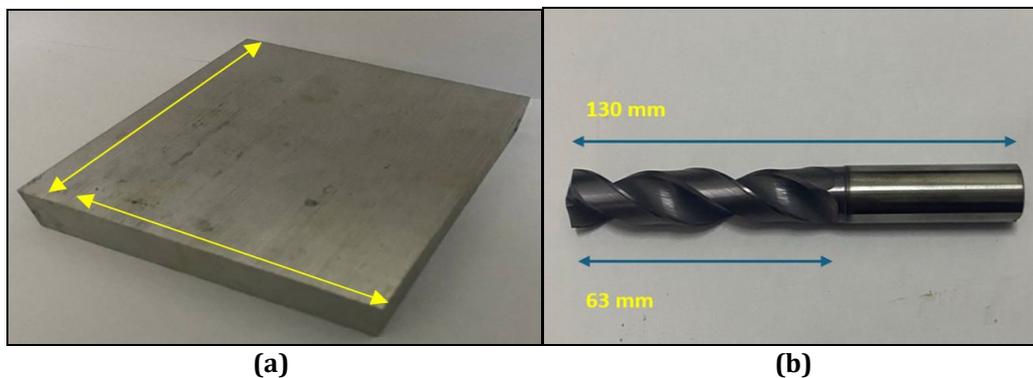


Fig. 1 (a) Aluminium Alloy (6061); (b) Carbide drill bit

Drilling involves creating holes through the workpiece, with measurements being taken at various points on the surface of the drilled holes in order to collect data regarding the drilling process. Figure 2 shows the model of the vertical machining centre used in this study, a MAZAK Nexus 410A-2. By using the tool maker microscope that was integrated into the machine, wear patterns such as scratched, grooved, and other irregularities on the drill bit can be identified, providing valuable insights into just how great the drill bit has performed throughout its lifetime as shown in Figure 2 (b). As a result, necessary adjustments can be made to focus on increasing efficiency and the longevity of the tool. As depicted in Figure 3, precision measurements were conducted using a Coordinate Measuring Machine (CMM) or Multi Probe techniques which was utilized [6] to calculate the diameter and cylindricity of the hole with precision using a CMM. During CMM measurements, the probe moves around the hole wall in a circular motion to capture discrete points on the surface for geometric analysis. A cylindricity measurement has been carried out using the software MCOSMOS to determine the diameter of the tube. The results are shown in Figure 4 where the distances from the measurement points to the cylinder's ideal axis are highlighted as maximum and minimum distances.

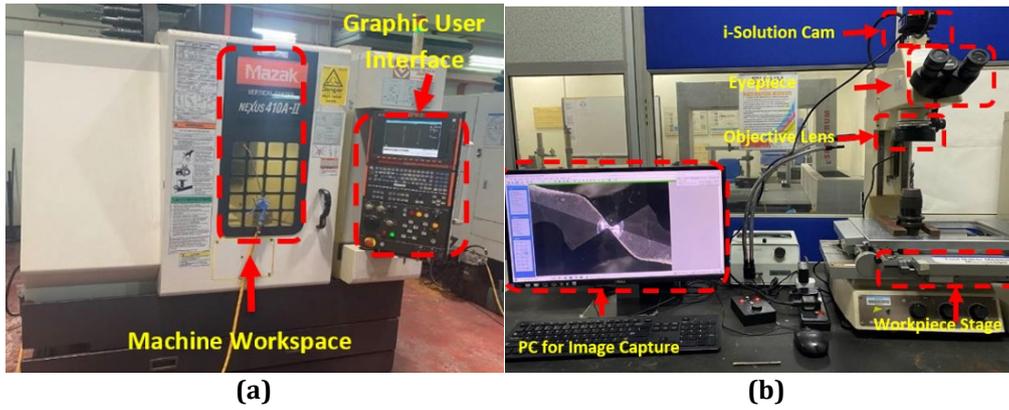


Fig. 2 (a) MAZAK Nexus 410A-2; (b) Setup drill bit on tool maker microscope for wear measurement

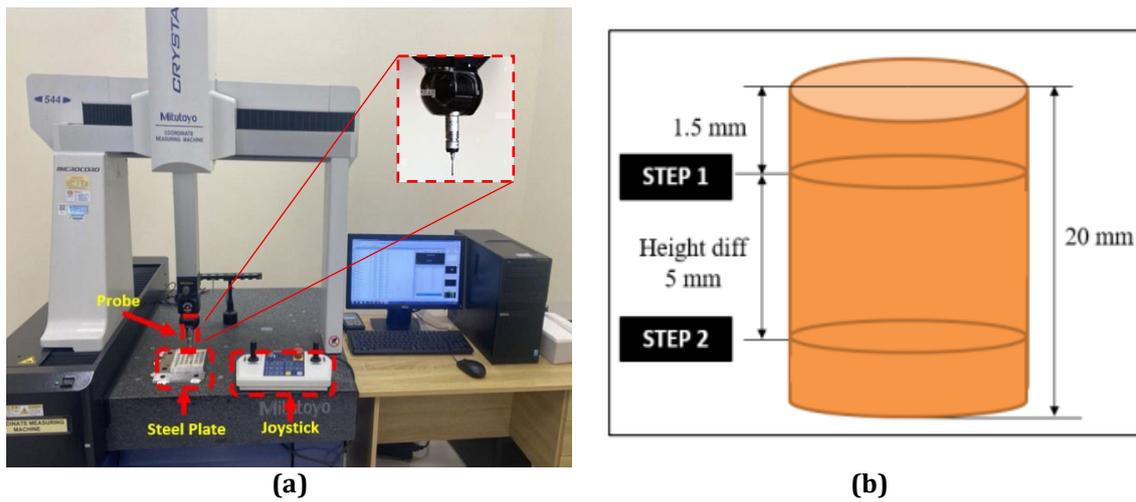


Fig. 3 (a) Setup for cylindricity measurements on CMM; (b) measurements of hole drilled

Figure 4 depicts the result of the cylindricity measurement as shown in MCOSMOS software, with a point of maximum distance from measuring points to the ideal axis, $\max\{R\}$ and another point of minimum distance from measuring points to the ideal axis, $\min\{R\}$.

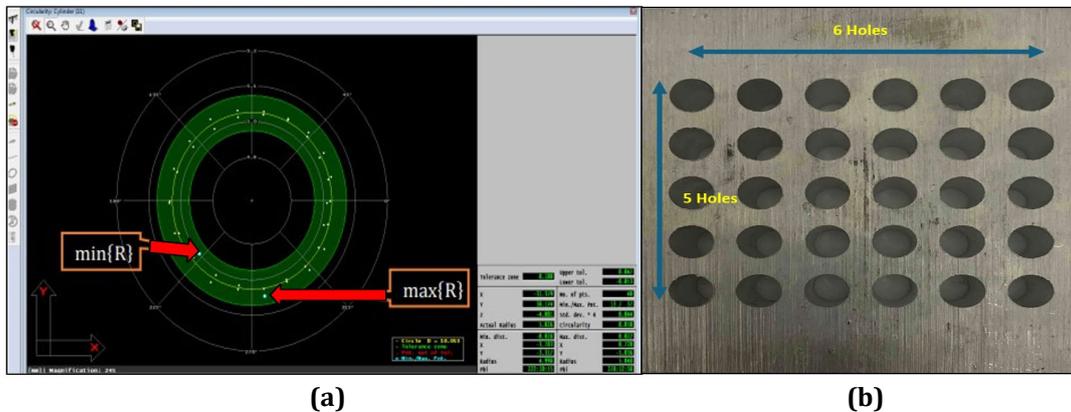


Fig. 4 (a) Cylindricity anatomy in MCOSMOS software; (b) 30 Holes on the workpiece

2.1 Experimental Setup

The experimental setup includes all the necessary instruments for conducting research on the manufacturing system while drilling is taking place. Table 1 provides information regarding the experimental settings of the

drilling machine, which includes the depth of cut, cutting speed, feed rate, coolant condition, and cutting insert among other variables. To complete the drilling experiment. A series of thirty holes, each measuring 9.8 mm in diameter, are drill in sequential order. Following the establishment of the drilling application, which includes the specification of the feed rate and cutting speed, the operation is then immediately started. Following the completion of the drilling process, the workpiece and the drill bit are removed. For wear analysis, a visual inspection is performed with the assistance of a toolmaker microscope, and measurements of wear are taken at holes. A Mitutoyo Coordinate Measuring Machine and MCOSMOS software are utilized to carry out the process of determining the cylindricity of a material by measuring it at specific hole points. The MCOSMOC software is responsible for recording and displaying the results of the automatic measurements of cylindricity. Every step of the process is repeated until all the holes that were chosen were to have been drilled.

Table 1 Experiment condition of drilling machine

Condition	Description
Parameter	Depth of Cut (mm) = 22 Cutting Speed, vc (m/min) = 31.4 Feed Rate, Fr (mm/rev) = 0.200, 0.230, 0.260, 0.290, 0.320, 0.360
Coolant Condition	Dry
Tool Drill	Carbide twist drill bit, 135° Point Angle

3. Result and Discussion

3.1 Experimental Setup

The analysis of tool wear has become increasingly complex due to the numerous factors that influence it. Variables such as the machining environment, cutting speed, feed rate, material hardness, tool material and geometry, cutting fluids, and workpiece characteristics all contribute to the wear process. In this experiment, the cutting speed is kept constant, while the feed rate is varied under dry drilling conditions to study the effects of tool wear, friction, and heat. High visibility allows for clearer observation and analysis of wear patterns on the drill bit, including heat cracking, flank wear, and crater wear. According to ISO 8688 standards, the maximum acceptable uniform wear is defined as a flank wear land width of 0.3 mm. Built-Up Edge (BUE) frequently forms on the drill bit's face during drilling at specified intervals between holes [7]. To mitigate this, a cleaning process is performed using cotton and alcohol, followed by the application of compressed air to ensure cleanliness and accuracy in subsequent measurements. Figure 5 shows the development of BUE on the flank tool edge.

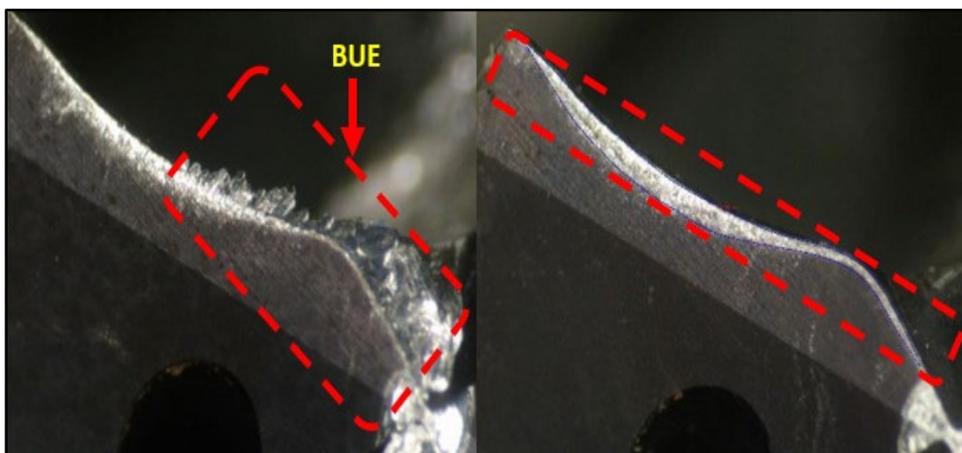
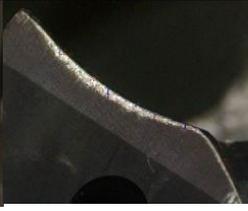
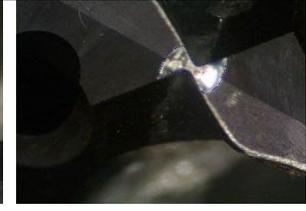
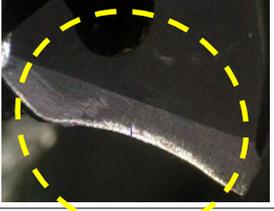
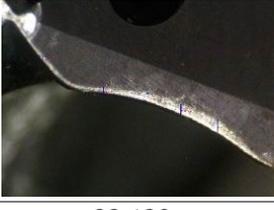
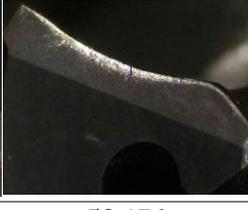
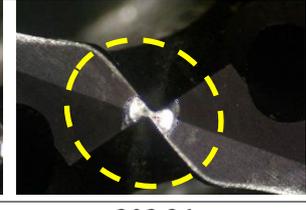
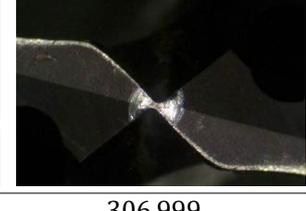
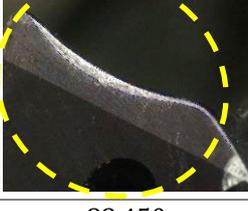
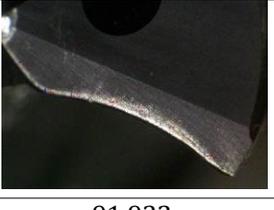
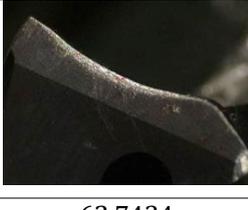
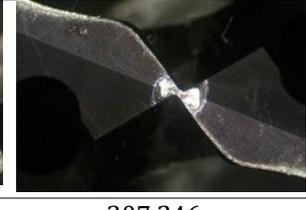


Fig. 5 Drill bit face with BUE and after cleaning process condition

The wear that occurred is focusing on the flank area. The picture will be captured into two parts of flank at the drill bit. The data for chisel edge wear is also collected to further optimize the findings.

Table 1 Experiment condition of drilling machine

Fr =0.230mm		Drill bit 2 (plate 2)		
Hole no	Flank 1	Flank 2	Chisel edge	
5				
μm	77.341	81.919	310.09	
10				
μm	79.955	86.459	318.952	
15				
μm	83.439	59.476	302.86	
20				
μm	90.590	55.772	306.999	
25				
μm	72.765	88.450	321.703	
30				
μm	91.932	62.7434	307.246	

Wear was predominantly observed at the chisel edge of the drill. This type of wear is typically induced by the high shear and compressive stresses present in the tool-workpiece contact zone, combined with elevated temperatures during drilling. The chisel edge, located at the drill tip, is the first area to engage with the workpiece during the drilling process [8]. In this experiment, the cutting speed was maintained consistently at 31.4 revolutions per minute across all drills, while the feed rate varied between drill 1 and drill 6. As illustrated in Figure 9, the results display an unstable pattern, attributed to errors in measuring tool wear. This instability is primarily due to frequent occurrences of Built-Up Edge (BUE) on the drill bit's surface. Despite cleaning efforts, remnants of BUE adhered to the drill bit, causing inaccuracies in the recorded wear measurements. The formation

of BUE during machining not only accelerates wear but also complicates data collection, making it challenging to accurately assess existing wear patterns [9]. Furthermore, misalignment and focusing issues emerged due to improper setup of the drill bit. Proper alignment and focus of the microscope are critical to ensuring accurate measurements, as deviations in these areas can result in erroneous data collection [10].

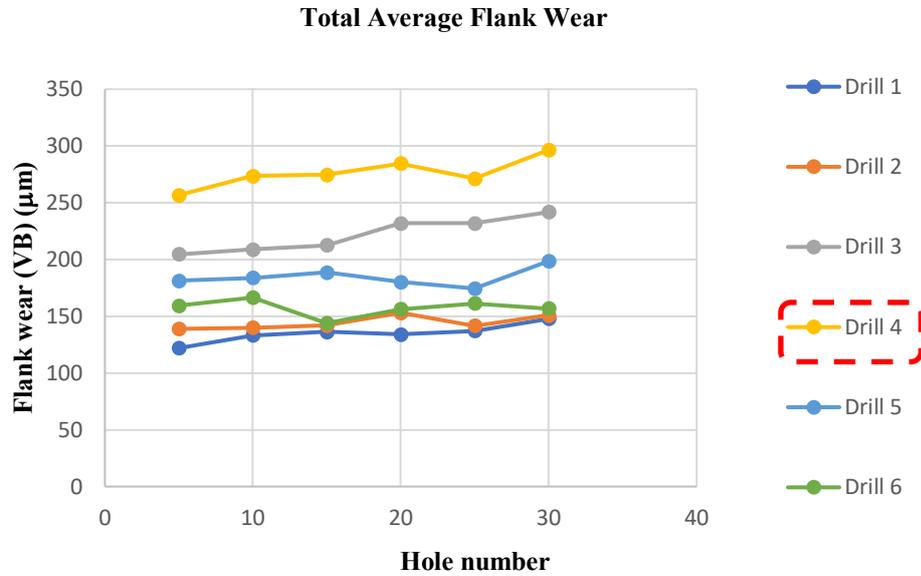


Fig. 6 Total average flank wear vs hole

The data presented in the Figure 6 indicate that drill bit 4 exhibited the highest level of flank wear compared to the other drill bits, while drill bit 1 showed the lowest flank wear. The lower wear observed in drill bit 1 will be attributed to its lower feed rate, which reduces the mechanical stresses and heat generated during the drilling process. In contrast, drill bit 4 experienced a higher feed rate, leading to greater tool wear. This trend is consistent with established findings, as tool wear generally increases with higher feedrates [11] due to the intensified friction and thermal loads imposed on the cutting edges during machining. Thus, the observed correlation between feed rate and tool wear further reinforces the importance of optimizing feed rate to prolong tool life and maintain machining efficiency.

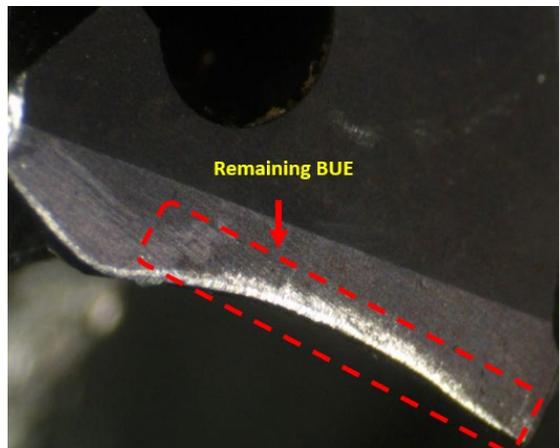


Fig. 7 Image of remaining BUE still occurred after cleaning processing

The variations in Built-Up Edge (BUE) formation likely contribute to the irregular wear patterns observed in the data. The cyclical formation and removal of Built-Up Edge (BUE) is able significantly impact the wear characteristics of specific hole sizes or drill bits, often resulting in unexpected variations in wear rates. Despite post-processing cleaning, residual BUE was still observed, which further complicated the accurate assessment of tool wear as shown in figure 7. These fluctuations may result in either an increase or decrease in wear, depending on the extent of BUE formation and removal during drilling. Additionally, the trend depicted in the graph suggests

that as the hole size decreases, the wear on the drill bit tends to increase [12]. This inverse relationship highlights the potential impact of hole size on tool wear during the machining process.

3.2 Cylindricity

Cylindricity measurements were taken for 30 holes across all drilled plates, with each hole measured at 90 points, using three points per hole. A Coordinate Measuring Machine (CMM) was employed for these measurements. The average cylindricity values were calculated for selected holes (5, 10, 15, 20, 25, and 30) across six plates. Drill bits 1, 2, and 6 exhibited generally stable or decreasing cylindricity measurements as hole size increased, suggesting a trend towards lower cylindricity with larger holes. However, variations in measurements between different hole sizes did not follow a strictly linear or consistent pattern. In contrast, drill bits 3, 4, and 5 displayed more irregular trends, with fluctuations in cylindricity that lacked a clear increasing or decreasing pattern across the range of hole sizes.

Drill bits 4 and 5 exhibited significantly higher cylindricity at hole size 20, leading to a distinct peak in their measurements as depicted in Figure 8. This increase in cylindricity can be attributed to heightened tool wear, which affects cylindricity values. This observation aligns with previous research, which indicates that as tool wear increases, cylindricity tends to decrease in subsequent holes due to the progressive degradation of the tool's cutting edge [13].

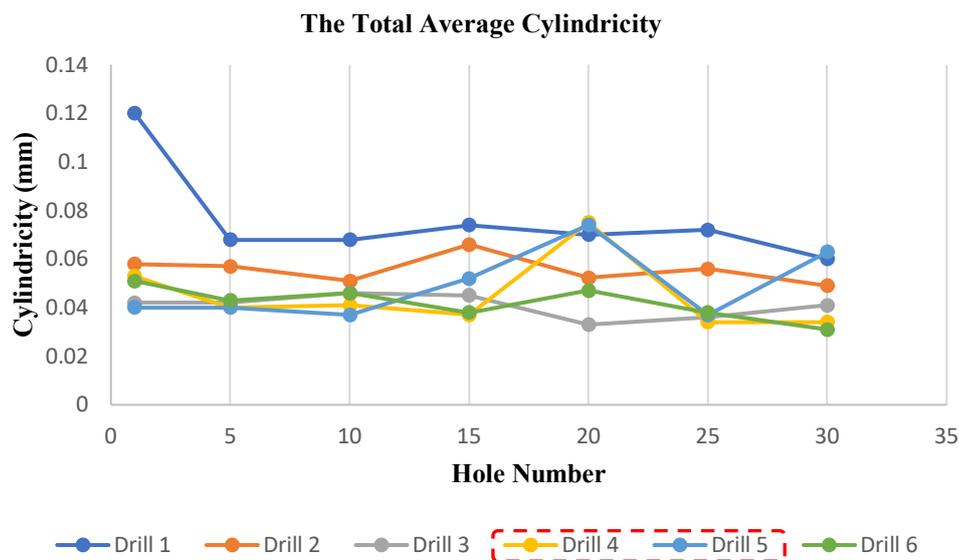


Fig. 8 Comparison of total average flank wear in different drill

3.3 The Correlation Between Tool Wear and Cylindricity

Figure 9 illustrates the relationship between tool wear and hole cylindricity as a function of feed rate. The data reveal that the trends for tool wear and cylindricity do not follow a similar or consistent pattern. There is no clear correlation indicating that an increase in average flank wear results in a corresponding increase in total average cylindricity. For instance, Drill 3 exhibits a relatively higher flank wear (0.1624) and cylindricity (0.0658), yet this relationship is not proportionate across all drills. This inconsistency may be attributed to data collection errors influenced by tool wear. Additionally, the formation of Built-Up Edge (BUE) on the drill bit further complicates accurate measurement of tool wear.

A correlation between tool wear and cylindricity was observed at feed rates ranging from 0.290 mm/rev to 0.360 mm/rev. The results indicate that as tool wear increases, cylindricity decreases. This finding is consistent with previous research, which suggests that tool wear significantly affects cylindricity by impacting the precision of the circular geometry. As tool wear progresses, it leads to a reduction in hole size and diminished cylindricity [13].

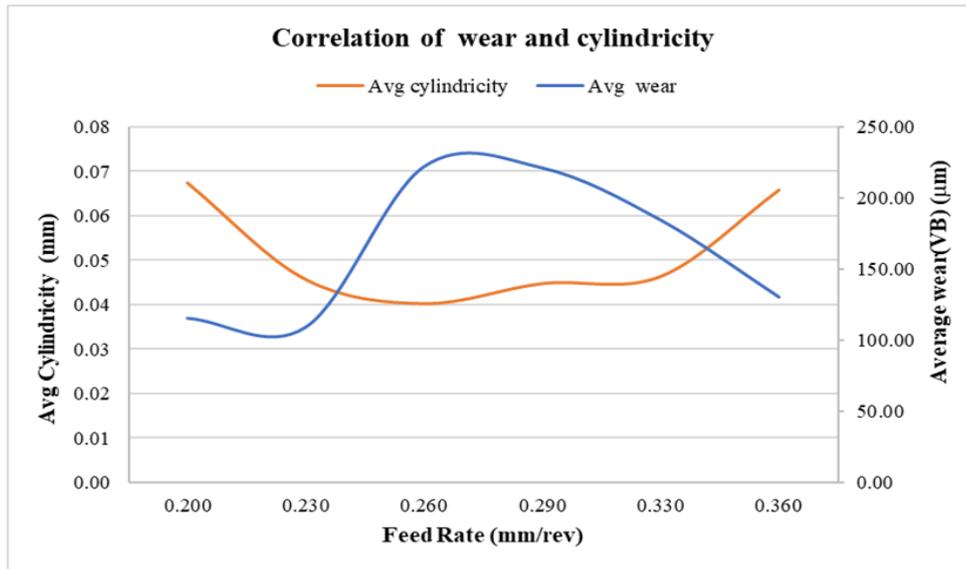


Fig. 9 Correlation between tool wear and cylindricity

4. Conclusions and Recommendations

The findings from the experimental analysis of tool wear and hole cylindricity during dry drilling of Al T6-6061 aluminum alloy are examined in detail in this section. Notably, human error contributed to some data discrepancies, highlighting the need for additional studies to refine data collection techniques in drilling operations for aircraft manufacturing. Ibrahim et al. [14] similarly emphasized the importance of accurate data collection to control surface roughness and mitigate the formation of Built-Up Edge (BUE) during drilling. In the present study, a feed rate of 0.260 mm/rev provided the best drilling performance, particularly with Drills 3 and 6. However, inconsistencies were noted with Drill 5 at a feed rate of 0.33 mm/rev, which could be attributed to residual BUE, making the assessment of tool wear more complex. These results are consistent with Ahmad et al. [15], who observed that BUE can affect chip formation and hole circularity, complicating the drilling process in aircraft component manufacturing. The significance of maintaining precise hole dimensions is particularly evident in the aerospace sector, where even minor deviations can result in manufacturing issues. This is further supported by the research of Ibrahim et al. [16], who explored the impact of structural accuracy in Wing-in-Ground (WiG) craft, underscoring the broader relevance of precision in the aerospace industry. To enhance the validity of these findings, future studies should aim to improve the experimental design by increasing the sample size of drilled holes, utilizing statistical correlation methods, and refining wear analysis techniques. This approach aligns with recommendations from Ibrahim et al. [17] and other researchers [18][19][20], who advocate for the use of advanced analytical methods to ensure more accurate and reliable data in mechanical engineering research.

Acknowledgement

The authors would like to express their gratitude to the Research Management Centre, UTHM for support this project by Collaborative Research Grant (Q071) and Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, for their valuable support throughout this research. Special appreciation is extended to HPMT Industries Sdn. Bhd., Shah Alam, for generously providing the necessary tools used as the primary instruments in this study.

Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Aishah Ahmad, Rasidi Ibrahim, Fadhil Supaat, Kamaruddin Kamdani; **data collection:** Fadhil Supaat; **analysis and interpretation of results:** Aishah Ahmad, Rasidi Ibrahim, Fadhil Supaat, Kamaruddin Kamdani; **draft manuscript preparation:** Aishah Ahmad, Rasidi Ibrahim, Fadhil Supaat, Kamaruddin Kamdani. All authors reviewed the results and approved the final version of the manuscript.

References

- [1] Beranoagirre, A., Urbikain, G., Marticorena, R., Bustillo, A., & López de Lacalle, L. N. (2019). Sensitivity analysis of tool wear in drilling of titanium aluminides. *Metals*, 9(3), 297. <https://www.mdpi.com/2075-4701/9/3/297>
- [2] Caggiano, A., Nele, L., & Teti, R. (2018). Drilling of fiber-reinforced composite materials for aeronautical assembly processes. In *Characterization of some composite materials*. IntechOpen. <https://doi.org/10.5772/intechopen.80466>
- [3] Gialanella, S., & Malandrucolo, A. (2020). *Gas turbine aero-engines*. Springer. https://doi.org/10.1007/978-3-030-24440-8_2
- [4] Ezugwu, E. O., Okeke, C. I., & Machado, A. R. (1998). High-speed threading of inclusion-modified steels with coated carbide tools. *Journal of Materials Processing Technology*, 86(1–3), 216–225. [https://doi.org/10.1016/S0924-0136\(98\)00313-6](https://doi.org/10.1016/S0924-0136(98)00313-6)
- [5] Chowdhury, M. S. I., Lajis, M. A., Che Haron, C. H., Ghani, J. A., & Rahman, M. M. (2017). Wear behaviour of coated carbide tools during machining of Ti6Al4V aerospace alloy associated with strong built-up edge formation. *Surface and Coatings Technology*, 313, 319–327. <https://doi.org/10.1016/j.surfcoat.2017.01.115>
- [6] Wang, Y., Li, L., Ni, J., & Huang, S. (2009). Form tolerance evaluation of toroidal surfaces using particle swarm optimization. *Journal of Manufacturing Science and Engineering*, 131(5), 051015. <https://doi.org/10.1115/1.4000103>
- [7] Venkatesh, V. C., & Xue, W. (1996). A study of the built-up edge in drilling with indexable coated carbide inserts. *Journal of Materials Processing Technology*, 58(4), 379–384. [https://doi.org/10.1016/0924-0136\(95\)02211-2](https://doi.org/10.1016/0924-0136(95)02211-2)
- [8] Zhou, J., & Yu, J. (2021). Chisel edge wear measurement of high-speed steel twist drills based on machine vision. *Computers in Industry*, 128, 103436. <https://doi.org/10.1016/j.compind.2021.103436>
- [9] List, G., Ghidossi, A., Rossi, A., DeBaets, A. P., & Dudzinski, D. (2005). Wear behaviour of cemented carbide tools in dry machining of aluminium alloy. *Wear*, 259(7–12), 1177–1189. <https://doi.org/10.1016/j.wear.2005.02.056>
- [10] Keller, H. E. (2007). Proper alignment of the microscope. In *Methods in Cell Biology* (Vol. 81, pp. 43–53). [https://doi.org/10.1016/S0091-679X\(06\)81003-4](https://doi.org/10.1016/S0091-679X(06)81003-4)
- [11] Suresh, R., Basavarajappa, S., & Gaitonde, V. N. (2015). Experimental studies on the performance of multilayer coated carbide tool in hard turning of high strength low alloy steel. *Journal of Materials Research*, 30(20), 3056–3064. <https://doi.org/10.1557/jmr.2015.236>
- [12] Abd Halim, N. F. H., Dahnel, A. N., Ismail, A. A., & Zainudin, N. A. (2020). An experimental investigation on drilling of aluminum alloy (Al 7075) using high speed steel cutting tools. *Test Engineering and Management*. <http://testmagazine.biz/index.php/testmagazine/article/view/7432/5650>
- [13] Sultan, A. Z., Sharif, S., & Kurniawan, D. (2015). Effect of machining parameters on tool wear and hole quality of AISI 316L stainless steel in conventional drilling. *Procedia Manufacturing*, 2, 202–207. <https://doi.org/10.1016/j.promfg.2015.07.035>
- [14] Ibrahim, M. R., Ahmad, A., Ibrahim, A., Samsudin, N. A., Mustapa, M. S., Cheng, K., & Chong, B. H. (2023). An effectiveness in manufacturing quality on surface roughness and built-up edge in drilling operation towards aircraft component. *Materials Science Forum*, 1110, 67–73. <https://doi.org/10.4028/p-v74xyf>
- [15] Ahmad, A., Ibrahim, R., Zainoridin, H., Chong, B. H., & Cheng, K. (2024). An analysis of chip formation and hole circularity in drilling applications: An aircraft components perspective. *Journal of Advanced Research in Applied Mechanics*, 118(1), 28–39. <https://doi.org/10.37934/aram.118.1.2839>
- [16] Ibrahim, M. R., Ahmad, A., Taufek, R. H., Hassan, S., Rahim, M. Z., Salleh, J. M. M., & Marwah, O. M. F. (2024). Investigation of lifting force affected by the velocity and angle of attack (AoA) in wing-in-ground (WiG) craft. *Journal of Advanced Research in Applied Mechanics*, 124(1), 99–112. <https://doi.org/10.37934/aram.124.1.99112>
- [17] Ibrahim, R., Saroni, I. S., Ahmad, A., Mohid, Z., Chong, B. H., & Abidin, R. (2024). Revolutionizing wing-in-ground effect: Investigating structural rigidity. *International Journal of Automotive and Mechanical Engineering*, 21(3), 11502–11511. <https://doi.org/10.15282/ijame.21.3.2024.4.0887>
- [18] Adeleke, A. K., Portillo Montero, D. J., Olu-lawal, K. A., & Olajiga, O. K. (2024). Statistical techniques in precision metrology: Applications and best practices. *Engineering Science & Technology Journal*, 5(3), 888–900. <https://doi.org/10.51594/estj.v5i3.944>

- [19] Rangineni, S., Bhanushali, A., Suryadevara, M., Venkata, S., & Peddireddy, K. (2023). A review on enhancing data quality for optimal data analytics performance. *International Journal of Computer Sciences and Engineering*, 11(10), 51–58. <https://doi.org/10.26438/ijcse/v11i10.5158>
- [20] Usiagu, G. S., Adefemi, A., Okoli, C. E., Dauda, C. D., & Olu-Lawal, K. A. (2024). Simulation techniques in industrial engineering: A USA and African perspective review. *Magna Scientia Advanced Research and Reviews*, 10(1), 265–272. <https://doi.org/10.30574/msarr.2024.10.1.0023>