© Universiti Tun Hussein Onn Malaysia Publisher's Office

JST

Journal of Science and Technology

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/jst

ISSN : 2229-8460 e-ISSN : 2600-7924

Comparison of Tool Wear Mechanisms During Drilling of Aluminium Alloy 7075 in Dry and Chilled Air Conditions

Nur Munirah Meera Mydin[1], Aishah Najiah Dahnel[1*], Natasha A. Raof[1], Norkhairusshima Muhamad Khairussaleh[1], Suhaily Mokhtar[1]

[1]Department of Manufacturing and Materials Engineering, International Islamic University Malaysia, 53100 Kuala Lumpur, Malaysia

*Corresponding Author

DOI: https://doi.org/10.30880/jst.2022.14.01.008

Received 28 February 2022; Accepted 14 June 2022; Available online 28 June 2022

Abstract: Aluminium alloys are widely used in manufacturing industry due to the need of lightweight components and low production cost. However, mechanical assembly of the alloy which requires drilling operations is challenging due to chip accumulation and heat at the cutting tool and workpiece interface. This often causes material adhesion on cutting edges, built-up edge, accelerated tool wear, shorter tool life and poor drilled hole quality. This paper investigates the effect drilling conditions (dry and chilled air at 10°C) on the wear mechanisms of tungsten carbide cutting tools during drilling Aluminium alloy 7075 (Al 7075) at two different feed rates. Chilled or cold air was used as a cooling medium in drilling Al 7075 to promote green manufacturing. Drilling operations of Al 7075 were performed at a constant cutting speed of 123 m/min with feed rates of 0.01 and 0.1 mm/rev. The cutting tools' flank wear were measured using an optical microscope with Dino-Capture software and further examination on the tool wear (e.g., built-up edge, built-up layer, and crack) were conducted using Scanning Electron Microscopy (SEM). The results of this study indicate that at higher feed rate of 0.1 mm/rev, adhesive wear is dominant due to the presence of evident material adhesion and fractures on the cutting edges. The use of chilled air was found to cause less material adhesion, however more edge fracture occurred which could be due to workpiece hardening. Therefore, it is inferred that drilling Al 7075 with chilled air requires harder and stronger cutting tool in order prolong the tool life.

Keywords: tool wear, drilling, chilled air, aluminium alloy

1. Introduction

The application of aluminium alloys (e.g. 6000 and 7000 series) in automotive industry has been evolving due to their high strength-to-weight ratio, high corrosion resistance and high fatigue strength [1]. However, the ductility of aluminium alloy is a major challenge when drilling operations are required to be performed since the material tends to adhere at the cutting tool. This can affect the longevity of cutting tool and the quality of holes produced. Thus, there is a need to investigate the drilling performance of aluminium alloy as drilling is a crucial manufacturing process, which is needed for parts assembly. In dry drilling, the major challenge is the high heat generated between the tool and workpiece interface. This often causes material adhesion on cutting edges, built-up edge, accelerated tool wear, shorter tool life and poor drilled hole quality. Previous studies found that the typical mechanisms of wear in drilling aluminium and its alloy are adhesion, abrasion and diffusion [2–5]. The factors involved in controlling tool wear mechanisms are workpiece materials, cutting condition, and cutting parameters, e.g. cutting speed and feed rate. Salguero, Batista, Marcos, & Go (2013) found that the formation of built-up edge had altered the cutting tool position angle, and this had resulted in poor machined surface finish [6]. The generation of adhesive wear can be categorized into two parts; the

*Corresponding author: aishahnajiah@iium.edu.my

primary is the direct adhesion between the cutting tool particles and the chips. Whereas, the secondary adhesion is caused by the interaction between the workpiece and cutting tool [7]. The material adhesion on the cutting edges accelerates the tool failure when the cutting tool particles were pulled out by the materials removed during the drilling operation. During drilling of B4C reinforced aluminium alloy, Taskesen & Kutukde (2013) found that as the cutting speed increases from 38 to 63 m/min, the flank wear at the centre till corner of the cutting edge also increases from 0.325 to 0.390 mm [8]. This is because of the maximum contact length and higher heat generation at the tool-workpiece interface during drilling. The wear due to cutting edge chipping was reported to be caused by the adhesion between the workpiece material and cutting tool surface [8].

Adhesion wear when drilling aluminium alloys have been prominent as the number of drilled holes increases due to heat buildup. The adhesion between the cutting edges and chip during drilling could lead to the formation of Built-Up Edge (BUE) and Built-Up Layer (BUL) [2]. Built-up edge occurs due to the material transfer through the chip from cutting tool. It is usually formed during drilling with the cutting parameters of lower cutting speeds and higher feed rates [9]. The formation of BUE and BUL is often reported to be caused by the diffusion process of the aluminium alloy to the cutting tool or vice versa when the cutting temperature is more than 750°C. This phenomenon had weakened the cutting tool and result in irregular cutting edge, thus, led to chipping and fracture at the cutting edge which could result in breakage of cutting tool [10]. In addition, Suryopratomo & Heinemann (2017) also reported the same issue on the formation of built-up edge in dry drilling of Al7050 that is due to the high cutting temperature of 55 °C [11]. In addition, abrasive wear could also occur when drilling aluminium alloys as reported by Zur-rayen et al. (2018) [12]. The study involved drilling ductile material using tungsten carbide cutting tools at feed rates of 0.09 mm/rev and a cutting speed of 70.4 m/min. The abrasion led to the loss of cutting tool strength, hence, increasing the flank wear rapidly. Pattnaik, Bhoi, Padhi, & Sarangi (2018) studied the dry machining of aluminium and found that there was eroded part of the tool rake face since the heat generation increases and the toughness and wear resistance of the cutting tool reduces as the machining continues [3]. Moreover, Nouari, List, Girot, & Géhin (2005) had investigated the effect of cutting speeds (25 to 165 m/min) in dry drilling of aluminium alloys and it had been found that at higher cutting speed of 165 m/min, the tool wear is maximum [3]. This is due to increment of cutting temperature that lead to transition of wear mechanisms from abrasion and adhesion then to diffusion. The increase in cutting temperature with large shear strains caused the deformation along the tool-chip interface and the primary shear zone, hence, diffusion occurs. The flow of work material along the contact surface carried away the atoms that are diffused from the tool to the chip. The material transfer towards the chip leads the formation of adhesion layer and a built-up edge at extreme cutting conditions. This will consequently lead to tool failure.

Drilling the alloys with cutting fluid is usually conducted to suppress the heat and hence reduce the issues. Cutting fluid could act as a cooling agent or as a lubricant in reducing the heat generated between the workpiece and cutting tool. However, the managing and disposal of the cutting fluid could increase production cost and lead to environmental pollution. The cutting fluid application in machining should follow the environmental requirements where it cannot be toxic or harmful to the human and environment. The use of chilled air as a coolant or lubricant is seen as an alternative for an oil and/or water free cutting fluid to dissipate the heat during drilling of aluminium alloys [13, 14]. Therefore, to investigate the performance of chilled air in drilling Al 7075, this paper reports the comparison of tool wear mechanism during drilling of Al 7075 in dry and chilled air conditions.

2. Material and Method

Drilling operations of Al 7075 alloy were performed using MAZAK Vertical Centre Nexus 410A-II machine that is equipped with the Mazatrol Matrix Nexus CNC controller, in dry and with chilled air (10°C). The drilling setup is shown in Fig. 1. Al 7075 plates having the composition as shown in Table 1, with a thickness of 13 mm were used throughout the drilling operations. Removable uncoated tungsten carbide (WC-Co) drills with the geometry as shown in Table 1 were used in drilling experiments. Drilling operations were conducted using a constant cutting speed of 123 m/min and feed rates of 0.01 and 0.01 mm/rev. These are based on the recommendation by cutting tool manufacturer.

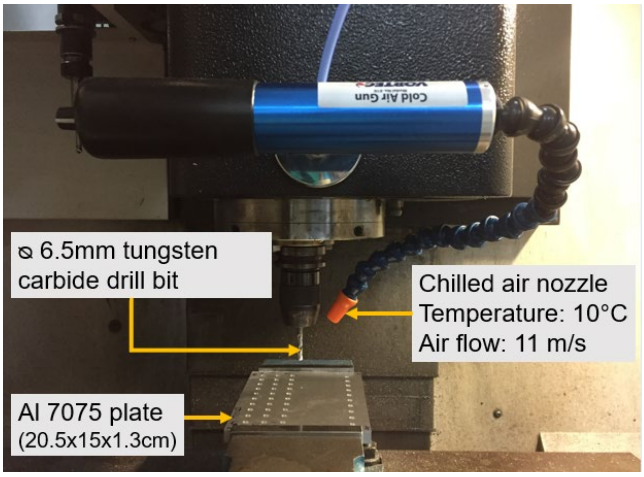


Fig. 1 - Drilling operation setup

Table 1 - Al 7075 composition (weight percentage)

Zn	Mg	Cu	Fe	Si	Mn	Ti	Cr	Al
5.1 – 6.1	2.1 – 2.9	1.2 – 2.0	0.5	0.4	0.3	0.2	0.18 – 0.26	remainder

Table 2 - Cutting tool geometry

Diameter	No. of flutes	Helix angle	Point angle	Flute length	Total length
6.5 mm	2	30°	118°	31 mm	70 mm

The wear was examined and measured at the flank faces of the drills as shown in Fig. 2. The images of cutting tool (WC-Co) flank wear were captured using Dino-Lite Digital Microscope Premier with magnification up to 250x and 5.0 Megapixels image resolution. Whereas, the flank wear was measured using Dino-Capture software. Further examination on the tool wear (e.g. BUE, BUL and crack) were conducted using Scanning Electron Microscopy (SEM).

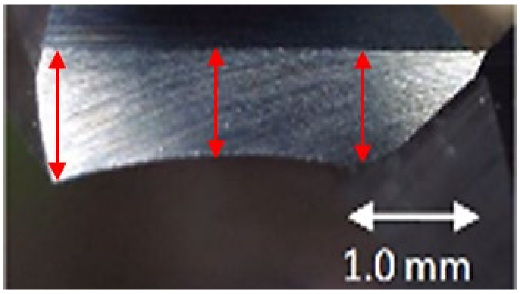


Fig. 2 - Flank face of the drill. The red arrows are the location of wear measurement

3. Results and Discussion

Fig. 3 shows the comparison of flank wear progression of the drills when drilling Al 7075 using 0.01 and 0.1 mm/rev in dry and with chilled air. It is apparent that, drilling with the higher feed rate of 0.1 mm/rev resulted in 67% higher tool wear compared to the lower feed rate of 0.01 mm/rev, for both dry and with chilled air. The observed increase in tool wear at the higher feed rate could be attributed to the higher material removal rate that generates higher thrust force during drilling aluminium 7075. As the feed rate increases, the tendency of chips accumulation at the cutting tool edge also increases since the material removal rate is higher. Thus, this had resulted in higher heat dissipation at the tool-chip interface, hence, accelerate the tool wear as number of holes produced increasing. Furthermore, at higher feed rate more workpiece material were removed per unit of time which could lead to higher stress on the cutting edges, which then result in higher cutting forces. This have been shown by previous studies which found that drilling with higher feed rate of 0.5 mm/rev resulted in higher cutting forces of 574 N and this was due to the increase in chip thickness, which then increase the power consumption in cutting [15]. During drilling aluminium 2024 alloy at higher feed rate of 0.9 mm/rev, the generation of cutting force is higher by 22% due to the higher material removal rate which consequently cause larger stress to the cutting tool, hence, led to rapid tool wear [16].

Fig. 4 and 5 shows the condition of cutting edges at the end of drilling operations. As can be seen from both Fig.s, the higher feed rate of 0.10 mm/rev exhibits noticeable deformation and wear on the cutting tool in the form of edge chipping, than the lower feed rate of 0.01 mm/rev. Regardless of cutting conditions, strong evidence of material adhesion and chipping was observed when drilling with the higher feed rate. This result can be be explained by the fact that higher feed rate means higher material removal rate where more material wear removed per unit time with thicker chip formation. This led to the workpiece accumulation and adhesion at the cutting edges which also resulted in the adhesive wear mechanism.

Another possible explanation for this might be that at high feed rate, the tools failed by cutting edge breakage as a result of adhesion wear especially in dry condition since the heat generation is higher. The chip thickness increases as the feed rate increases where this required higher consumption of cutting power that led to higher heat generation. As in Fig. 4 (a) and 5 (a), more adhesion was observed in dry drilling which indicated more heat generation compared to drilling with chilled air as shown in Fig. 4 (b) and 5 (b). This findings agree Diniz, Machado, & Corrêa (2016) and Fernandez-Vidal, Batista, & Salguero (2018), whose stated that in dry condition, the occurrence of adhesive wear was dominant since the particles of cutting tool were removed along with the chip flow due to the adhesion mechanism [7,17].

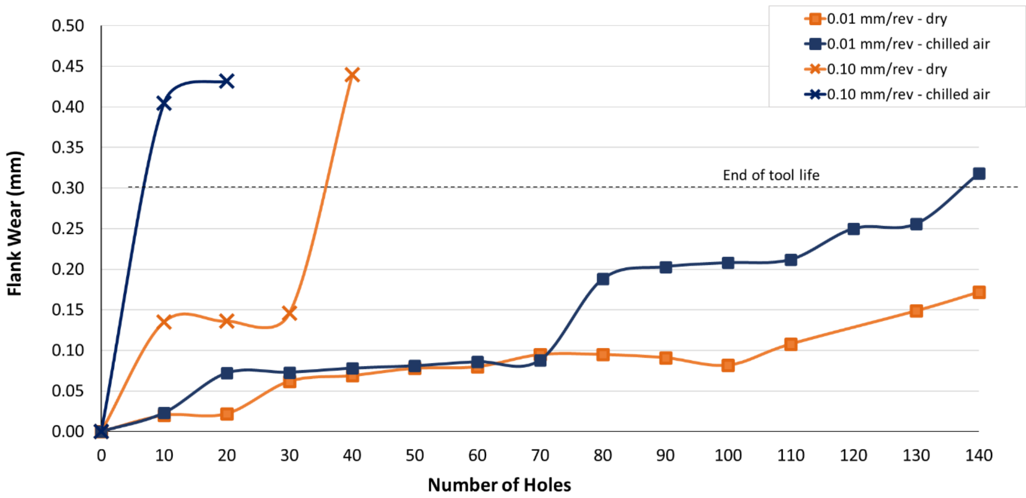
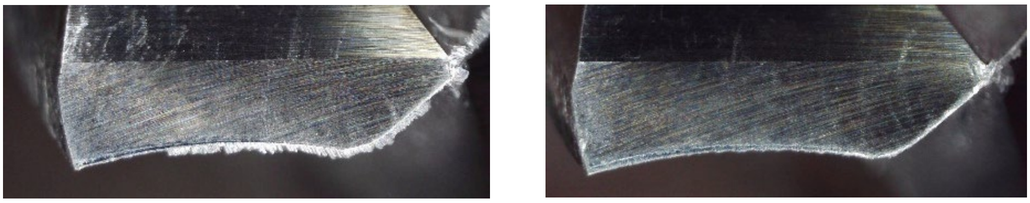


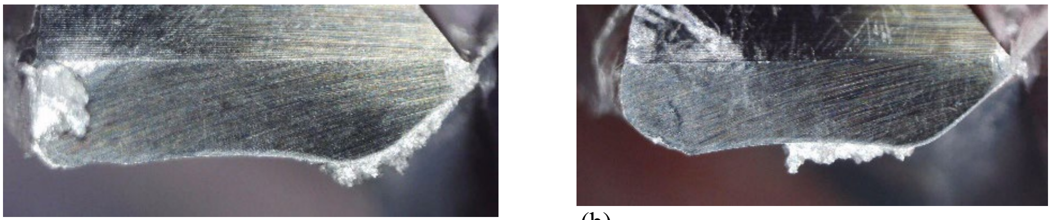
Fig. 3 - Flank wear when drilling Al 7075 at a constant cutting speed of 123 m/min and feed rates of 0.01 and 0.1 mm/rev in dry and with chilled air

The use of chilled air was found to cause less material adhesion, however, the tool wear accelerated due to cutting edge fracture, chipping and fracture. It seems possible that this result is due to the poor heat dissipation and workpiece hardening which cause by the chilled air. In dry drilling, the typical range of temperature for cutting speeds with range of 70 – 200 m/min was around 200°C and in this study, the cutting speed is 123 m/min [2]. Therefore, with application of chilled air cutting temperature can be reduced to a certain percentage only. This can be proved by previous study from Zhaoju Zhu et. al (2020) where in drilling aluminium 2024 at cutting speed and feed rate of 100 m/min and 0.3 mm/rev, chilled air reduced the cutting temperature by 14% (52°C) [18]. The results, as shown in Fig. 3, indicates that the lowest flank wear when drilling aluminium 7075 alloy was achieved when using lower feed rate due to less volume of material removed per one tool rotation at low feed rate, hence less material adhesion and chipping.



(a) (b)

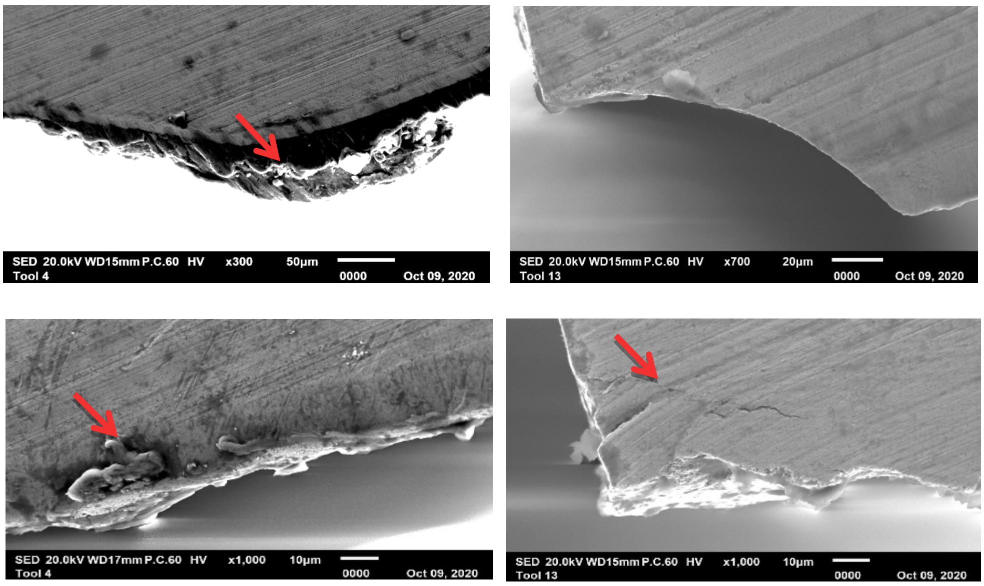
Fig. 4 - Cutting edge condition after drilling 140 holes at the feed rate of 0.01 mm/rev (a) in dry; and (b) with chilled air



(a) (b)

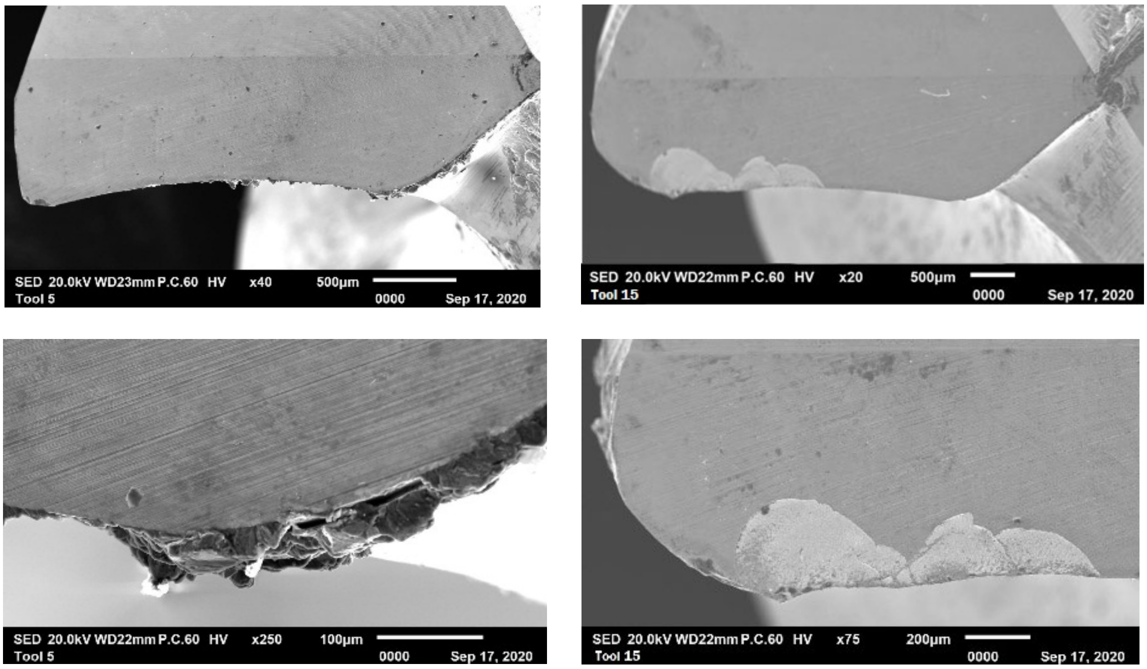
Fig. 5 - Cutting edge condition after drilling 140 holes at the feed rate of 0.1 mm/rev (a) in dry; and (b) with chilled air

Fig. 6 and 7 show the condition of cutting edge where the difference in between dry and chilled air condition are evident in term of material adhesion and chipping. As mentioned previously, during drilling process, chilled air act as a cooling medium which caused lack material adhesion and built-up edge formation since the heat generated had been dissipated. This shows that the presence of chilled air (10°C) in drilling process help to reduce the formation of built-up edge, hence, lower the development of adhesive wear that will affect the performance and life of the cutting tool. However, the use of chilled air resulted in more fracture and chipping as shown in Fig. 6 (b) which is likely due to workpiece surface hardening as a result of exposure of chilled air before drilling was performed. This is supported by the previous study of Xu et al., (2020) who found that the hardness of Al6061 alloy sheet increased by 60% due to the alloy grain size reducing when being air cooled [19]. The workpiece surface hardening explained the higher tool wear rate and shorter tool life when drilling with chilled air than dry drilling. In addition, the strength of workpiece was maintained throughout the drilling since the heat generated at the tool-workpiece interface was dissipated by the chilled air.



(a) (b)

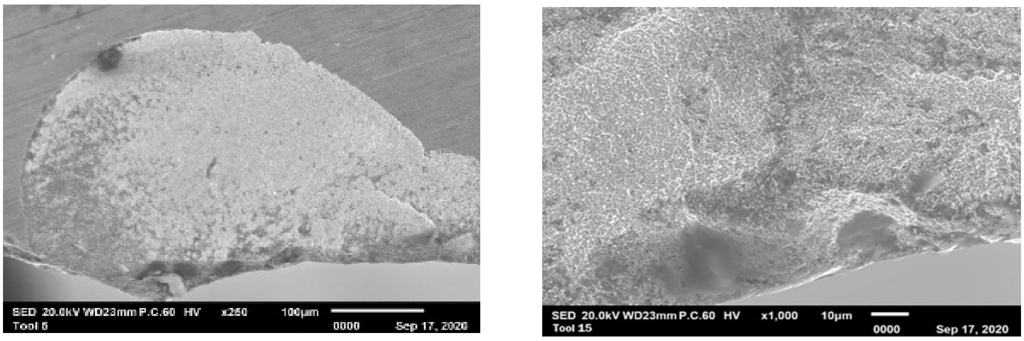
Fig. 6 - SEM micrographs of cutting tool after drilling 140 holes at the feed rate of 0.01 mm/rev (a) in dry; and (b) with chilled air



(a) (b)

Fig. 7 - SEM micrographs of cutting edge after drilling 140 holes at the feed rate of 0.1 mm/rev (a) in dry; and (b) with chilled air

The material adhesion can be related to the flow-zone where the chip is removed to the tool rake face is the most dominant heat resources that responsible for increment of the tool temperature. As the number of holes produced increases, the amount of chip generated also increases. Thus, the cutting temperature of tool interface and workpiece is significantly increasing. As the cutting temperature increases, the workpiece material will adhere at the cutting edge in significant amount consequently resulting in BUE (Build Up Edge) formation [20]. Adhesive mechanism and higher cutting forces acting on the tool in dry machining cause the edge chipping. Chipping could occur at the tool nose of a drill which causes a change in the cutting tool geometry as the rake angle may become negative. Chipping usually occurred at the flank face and it is often happened in dry condition since there is no medium to cool the heat generated. Besides, as shown in Fig. 6 (a) adhesion wear was found significantly at the higher feed rate where there was accumulation of workpiece attached to the tool cutting edge. This is also happened due to the high temperature of cutting in dry machining. Thus, in order to avoid this higher tool wear, higher feed rate is typically not recommendable in dry machining [21]. In contrast, the dominant wear mechanism at low feed rate of 0.01 mm/rev is abrasive wear as in Fig. 6, where the smooth cutting edge indicates abrasion occurred. Fig. 8 shows the SEM image at higher magnification of fracture which is apparent along the cutting edges for drilling with chilled air. This fracture indicates that the cutting tool had experienced higher stress from the drilling process of aluminium alloy 7075. A possible explanation for this is that the workpiece had been hardened by the presence of chilled air and throughout the drilling process, the workpiece properties was maintained.



(a) (b)

Fig. 8 - SEM micrographs on evidence of edge fracture at feed rate of 0.1 mm/rev with chilled air

During drilling process, the grain structure was changing accordingly, so, when there is presence of lower temperature air, the grains size also affected where the grains size reduced due to the elongation after chilled deformation. As the grain size was getting smaller, the arrangement of the workpiece particles near the grain boundaries was getting compact. This had resulted in higher resistance of workpiece towards the external force, which is the cutting tool itself. Hence, as the workpiece had been chilled deformed, their properties in term of strength and hardness increases. This result is consistent with previous study of [22] where the hardness of aluminium silicon alloy increases from 1.23 GPa to 1.49 GPa as the cooling rate increases from 77 to 168 K/min due to the reduction in size of grains. As the grains size decreases, this led to smaller repulsion stress of silicon particles boundary dislocation and result in higher requirement of applied stress to broaden dislocations across the workpiece material. Thus, this is the reason on more fracture at cutting tool edge when drilling in chilled air condition than dry.

4. Conclusions

This study shows that the use of chilled air during drilling Al 7075 resulted in less material adhesion on cutting tool than dry drilling. However, higher tool wear was observed when using the higher feed rate of 0.1 mm/rev. This is because higher feed rate results in more material removed per tool rotation which induced higher stress on the cutting edges. Furthermore, as the feed rate increases, the tendency of chips accumulation at the cutting tool edge also increases since the material removal rate is higher. Thus, this had resulted in higher heat dissipation at the tool-chip interface, hence, accelerating the tool wear as number of holes produced increasing. The adhesive wear is dominant at higher feed rate of 0.1 mm/rev as there is evident material adhesion and fracture on the cutting edges. Whereas, at lower feed rate of 0.01 mm/rev, abrasive wear was found to be dominant. For both feed rates, the application of chilled air caused higher tool wear by cutting edge fracture that occurred due to workpiece hardening. The long exposure time of chilled air to the workpiece can cause hardening of the workpiece surface which would lead to higher stress on the cutting edges to remove the Al 7075 workpiece, hence more edge fracture occurred. Therefore, it is inferred that drilling with chilled air requires harder and stronger cutting tool in order prolong the tool life.

Acknowledgement

The research and finding described in this paper were supported by Fundamental Research Grant Scheme from the Ministry of Education, Malaysia. Reference Code: FRGS/1/2018/TK03/UIAM/03/5

References

[1] M. Aamir, K. Giasin, M. Tolouei-rad, and A. Vafadar, “A review : drilling performance and hole quality of,” Integr. Med. Res., vol. 9, no. 6, pp. 12484–12500, 2020.

[2] F. Girot, M. E. Gutiérrez-Orrantia, M. Calamaz, and D. Coupard, “Modeling and adhesive tool wear in dry drilling of aluminum alloys,” AIP Conf. Proc., vol. 1315, no. 1, pp. 1639–1644, 2010.

[3] S. K. Pattnaik, N. K. Bhoi, S. Padhi, and S. K. Sarangi, “Dry machining of aluminum for proper selection of cutting tool: tool performance and tool wear,” Int. J. Adv. Manuf. Technol., 2018.

[4] M. Nouari, G. List, F. Girot, and D. Géhin, “Effect of machining parameters and coating on wear mechanisms in dry drilling of aluminium alloys,” Int. J. Mach. Tools Manuf., vol. 45, no. 12–13, pp. 1436–1442, 2005.

[5] M. C. Santos, A. R. Machado, W. F. Sales, M. A. S. Barrozo, and E. O. Ezugwu, “Machining of aluminum alloys: a review,” Int. J. Adv. Manuf. Technol., vol. 86, no. 9–12, pp. 3067–3080, 2016.

[6] J. Salguero, M. Batista, M. Marcos, and A. Go, “Analysis of the evolution of the Built-Up Edge and Built-Up Layer formation mechanisms in the dry turning of aeronautical aluminium alloys,” vol. 302, pp. 1209–1218, 2013.

[7] S. R. Fernandez-Vidal, S. Fernandez-Vidal, M. Batista, and J. Salguero, “Tool wear mechanism in cutting of stack CFRP/UNS A97075,” Materials (Basel)., vol. 11, no. 8, 2018.

[8] A. Taskesen and K. Kutukde, “Analysis and optimization of drilling parameters for tool wear and hole dimensional accuracy in B4C reinforced Al-alloy,” Trans. Nonferrous Met. Soc. China (English Ed., vol. 23, no. 9, pp. 2524–2536, 2013.

[9] J. Y. Kao, C. Y. Hsu, and C. C. Tsao, “Experimental study of inverted drilling Al-7075 alloy,” Int. J. Adv. Manuf. Technol., vol. 102, no. 9–12, pp. 3519–3529, 2019.

[10] M. Uddin, A. Basak, A. Pramanik, S. Singh, G. M. Krolczyk, and C. Prakash, “Evaluating hole quality in drilling of Al 6061 alloys,” Materials (Basel)., vol. 11, no. 12, pp. 1–14, 2018.

[11] E. Suryopratomo and R. Heinemann, “Investigation of Hole Quality and Tool Wear in High-Speed Drilling of Al 7050,” Mech. Eng. An Int. J., vol. 434, no. 12, pp. 1–10, 2017.

[12] M. Zurrayen et al., “Characterization of tool wear in friction drilling,” J. Tribol., vol. 17, no. April, pp.

93–103, 2018.
[13] J. Liu and Y. Kevin Chou, "On temperatures and tool wear in machining hypereutectic Al-Si alloys with vortex-tube cooling," Int. J. Mach. Tools Manuf., vol. 47, no. 3–4, pp. 635–645, 2007.
[14] P. Asok and P. Chockalingam, "Dry and compressed air cooling comparative study on 6061 aluminium alloy drilling using coated drill," Adv. Mater. Res., vol. 903, no. February 2014, pp. 45–50, 2014.
[15] Z. Zhu, B. He, and J. Chen, "Evaluation of tool temperature distribution in MQL drilling of aluminum 2024-T351," J. Manuf. Process., vol. 56, no. January, pp. 757–765, 2020.
[16] K. Giasin, A. Hodzic, V. Phadnis, and S. Ayvar-Soberanis, "Assessment of cutting forces and hole quality in drilling Al2024 aluminium alloy: experimental and finite element study," Int. J. Adv. Manuf. Technol., vol. 87, no. 5–8, pp. 2041–2061, 2016.
[17] Diniz, A. E., Machado, Á. R., & Corrêa, J. G. (2016). Tool wear mechanisms in the machining of steels and stainless steels. International Journal of Advanced Manufacturing Technology, 87(9–12), 3157–3168. https://doi.org/10.1007/s00170-016-8704-3
[18] Zhu, Z., He, B., & Chen, J. (2020). Evaluation of tool temperature distribution in MQL drilling of aluminum 2024-T351. Journal of Manufacturing Processes, 56(January),757–765. https://doi.org/10.1016/j.jmapro.2020.05.029
[19] Xu, Z., Wang, S., Wang, H., Song, H., Li, S., & Chen, X. (2020). Effect of Cooling Rate on Microstructure and Properties of Twin-Roll Casting 6061 Aluminum Alloy Sheet. Metals, 1-11
[20] Jindal, A. (2012). Analysis of Tool Wear Rate in Drilling Operation using Scanning Electron Microscope (SEM). Journal of Minerals and Materials Characterization and Engineering, 11(01), 43–54. https://doi.org/10.4236/jmmce.2012.111004
[21] Khatri, A., & Jahan, M. P. (2018). Investigating tool wear mechanisms in machining of Ti-6Al-4V in flood coolant, dry and MQL conditions. Procedia Manufacturing, 26, 434–445. https://doi.org/10.1016/j.promfg.2018.07.051
[22] E. Lee and B. Mishra, "Effect of solidification cooling rate on mechanical properties and microstructure of Al-Si-Mn-Mg Alloy," Mater. Trans., vol. 58, no. 11, pp. 1624–1627, 2017.