Journal of Engineering Science and Technology
Vol. 15, No. 1 (2020) 128 - 138

TOOL LIFE AND SURFACE ROUGHNESS IN DRY HIGH SPEED MILLING OF ALUMINUM ALLOY 7075-T6 USING BULL NOSE CARBIDE INSERT

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Abstract

The paper reports the findings of the experimental work to study the impact of machining parameters, particularly cutting speed, feed rate, and axial depth of cut towards cutting tool life and machined surface roughness in high-speed milling aluminium alloy 7075-T6 with bullnose cutter under dry environment. Previous studies found that tool life and surface roughness in machining aluminium alloy 7075-T6 using cemented carbide are unfavourable compared to other materials. However, this observation needs further study. Thus, a raw block of aluminium alloy 7075-T6 was proposed in this experiment. An eight-run experiment was designed according to full factorial design based on two levels of cutting speed (500 m/min, 600 m/min), feed rate (0.12 mm/tooth, 0.15 mm/tooth), and axial depth of cut (1.40 mm, 1.70 mm) and then analysed employed ANOVA. Cutting tool life was restricted by tool wear in the milling process. The microscope and portable surface roughness tester were employed to analyse tool wear and average surface roughness value. Cutting speed and feed rate were found to be a significant factor to the tool life and surface roughness. The longest tool lifespan of 16.79 minutes and lowest surface roughness value of 0.595 µm were determined at a speed of 500 and 600 m/min, respectively, with a low combination of the rest of parameter, which are 0.12 mm/tooth and 1.40 mm.

Keywords: Aluminum alloy 7075-T6, Dry environment, Machining parameter, Surface roughness, Tool life.

1. Introduction

In recent decades, the application of aluminium alloy has been widely trending in the aerospace industry as the primary material in producing complex components that constitute the major aircraft structural components as well as provide the superior ability to reduce weight, production cost, and fuel consumption. It has ductility to allow the material to deform prior to brittle failure [1]. The harder grade from the 7000 series aluminium alloys with relatively high zinc content has been applied because of possessing the potential to empower the high strength over the military and commercial aircraft parts including the fuselages and wing skins [2-5]. It is driven by overwhelming characteristics like moderate hardness, moderate toughness, good corrosion resistance, good tensile strength, and heat treatable [6-8]. Due to these characteristics, aluminium alloy 7075-T6 is ideally one of the 7000 series primarily employed in aircraft components manufacturing in which, reinforced by age hardening [9, 10].

Based on studies by Cai et al. [11], this material is synonymous with the dry milling at high-speed cutting in the endeavour to attain a good surface finish as well as serving the reduced maintenance cost and improved productivity. In addition, the practicability of dry machining in the aerospace industries is seen receiving much attention because of the fact associated with cutting fluid cost is approximately about 17% of the total manufacturing cost [12-15]. Dry machining has desired functions towards the machined surface quality and health of machine operators due to its contribution in eliminating all the severe impacts correlated with the application of cutting fluids for cooling or lubricating purposes [16-19]. Nevertheless, there are common challenges in the milling of aluminium alloy 7075-T6 particularly lessen cutting tool life and poor surface roughness, which of both are affecting the performance of machinability. It is occurred due to, resulting from the adhesion and build-up layer (BUL) formation during the milling process [20, 21]. Suresh Kannan and Ghosh [22] carried out an experiment to appraise the performances of a hydrogenated diamond-like carbon (H-DLC) coating on carbide end mills in the machining of aluminium alloy 7075-T6. They revealed that this aluminium was found to offer less-severe aluminium adhesion than pure aluminium perhaps because of the presence of alloy elements such as zinc and copper as well as the coating on the tool was could to significantly avoid BUL formation at a high range of cutting speed. Thus, the dominant machining parameters including cutting speed, feed rate, and depth of cut are deemed in plays an essential role to gain prolonged cutting tool lifespan and justifiable surface quality.

This paper presents the impacts of dry high-speed milling with bullnose cutter on the tool life and surface roughness of aluminium alloy 7075-T6. The selection of machining parameters has explored profoundly in order to provide good results.

2. Materials and Methods

The experiments were performed on DECKEL MAHO DMU 50eVolution CNC milling 5-axis machine that is equipped alongside reachable spindle speed at 16000 rpm and feed of 20000 mm/min. The elected workpiece material was an aluminium alloy 7075-T6 the dimension of 300 mm, 150 mm, and 40 mm representing length, width, and thickness, respectively. The chemical structure of aluminium alloy 7075-T6 was 90.3% Al, 5.6% Zn, 2.5% Mg, and 1.6% Cu according to the manufacturer. The cutting tool employed is the insert and tool holder that was commercially manufactured by Sumitomo. The insert is cemented carbide with the designation of QPMT 10T335PPEN was mounted on a 14 mm nominal diameter single flute tool holder WRC10016ES as exhibited in Fig. 1. The tool holder had an overhang, which is 50 mm aluminium maintained throughout the experiment in order to avoid the possibility of causing deflection and vibration. The thickness of the workpiece is almost 1 mm was skimmed off in eliminating any surface defects that could adversely compromise the machining outcome. The machining parameters for dry high-speed milling included cutting speed (v_c), feed rate (f_z), and axial depth of cut (a_p) are as exhibited in Table 1 in while the step-over (a_e) restricted to 7 mm. The machining parameters are selected after taking into account the gap analysis involving the milling operation based on the previous research.

The tool life criterion was determined when reached tool flank wear (*vb*) of 0.30 mm or catastrophic failure based upon ISO 8688-2-1989 [23]. Tool flank wear was observed and measured at every cutting time using an optical microscope in which, manufactured by Olympus BX53M. In addition, the surface roughness (Ra) values were measured on the machined surface using Mitutoyo Surftest SJ-210 portable surface roughness tester and cut-off distance was set at 0.80 mm. The measurement of Ra values was taken at three different locations for every pass interval in the perpendicular direction to feed and afterwards the Ra average was computed. Statistical software via Minitab was utilized for the ease of designing the experiments carried out. The experiments designed in accordance with full factorial design at three different factors and two different levels wherein a total of eight runs were generated based on combinations of parameters. Analysis of Variance (ANOVA) was employed to discover the correlation between machining parameters and define the machining parameters most influencing tool life and surface roughness.

Fig. 1. Bull nose mill employed in the experiment work.

Table 1. Machining parameter employed in the experiment.

Factor	Level	
	-1	+1
Cutting speed (v_c), m/min	500	600
Feed rate (f_z), mm/tooth	0.12	0.15
Axial depth of cut (a_p), mm	1.40	1.70

3. Results and Discussion

Table 2 presents the outcome of cutting tool life and machined surface roughness with full factorial design. A total of eight runs order was obtained.

Table 2. Result of tool life and surface roughness.

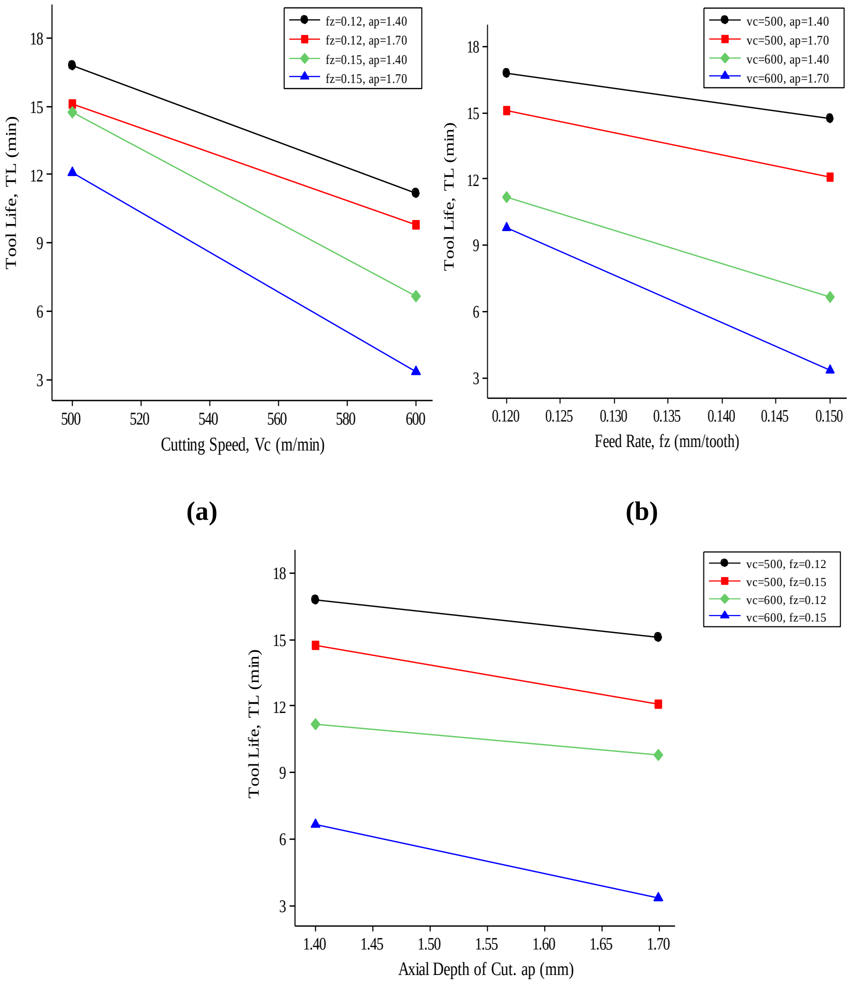
No.	Cutting speed (v_c), m/min	Feed rate (f_z), mm/tooth	Axial depth of cut (a_p), mm	Tool life (T_L), min	Surface roughness (Ra), µm
1	500	0.12	1.40	16.79	0.772
2	500	0.12	1.70	15.11	0.804
3	500	0.15	1.40	14.77	0.851
4	500	0.15	1.70	12.09	0.907
5	600	0.12	1.40	11.19	0.595
6	600	0.12	1.70	9.79	0.635
7	600	0.15	1.40	6.71	0.681
8	600	0.15	1.70	3.36	0.762

Tool life is referred to the total cutting time when reaches the end point of wear. It is strongly swayed by the temperature generated in the cutting zone. From Table 2, the results of the tool life revealed that the lifespan between about 3.36 and 16.79 minutes was recorded during the work was performed. Longer tool life beyond 16.79 minutes was served in cutting speed of 500 m/min, the feed rate of 0.12 mm/tooth, and axial depth of cut of 1.40 mm. 3.36 minutes is the shortest life span in the dry high-speed milling of aluminium alloy 7075-T6, in which, has occurred at 600 m/min, 0.15 mm/tooth, and 1.70 mm represent cutting speed, feed rate, and axial depth of cut, respectively.

Figures 2(a) to (c) displays the effect of the varying machining parameter towards cutting tool lifespan after dry milled with the cemented carbide bullnose. Prolonged tool lifespan was obtained by a decrease in cutting speed, feed rate, and axial depth of cut as depicted in Fig. 2(a). Whilst, the shortest tool life was obtained in the opposite way, namely increases the value in the cutting speed, the feed rate, and also an axial depth of cut. However, Khorasani et al. [24] revealed that the moderate value in cutting speed and lowest value of feed rate tend to the longest tool life in the study of the correlation of machining parameters in the end milling of aluminium 7075-T6, namely cutting speed, feed rate, and depth of cut on tool life using Artificial Neural Networks (ANN). The contradicting machining parameters were suspected due to a small ability of machine tool in achieving a longer tool life. Apart from that, Fig. 2(b) exhibits the effect of the feed rate on the tool life in which, it decreases as the feed rate increases from 0.12 to 0.15 mm/tooth.

The shortest tool life was produced beyond 3.36 minutes at a feed rate of 0.15 mm/tooth in a speed of 600 m/min. The longest tool lifespan of 16.79 minutes produced at a feed rate of 0.12 mm/tooth at a speed of 500 m/min. It shows that a longer tool lifespan can be achieved at a low feed rate. In addition, Fig. 2(c) exhibits the effect of axial depth of cut towards tool life at each difference of cutting speed and feed rate.

Obviously, the increment of the axial depth of cut has decreased tool lifespan. The longest and shortest lifespan, which is 16.79 and 3.36 minutes were produced in the respective axial depth of cut of 1.40 and 1.70 mm at a speed of 500 and 600 m/min. It reveals that a low axial depth of cut slows down the progression of tool wear, thus, promotes the longer tool lifespan.



(a) **(b)**

(c)

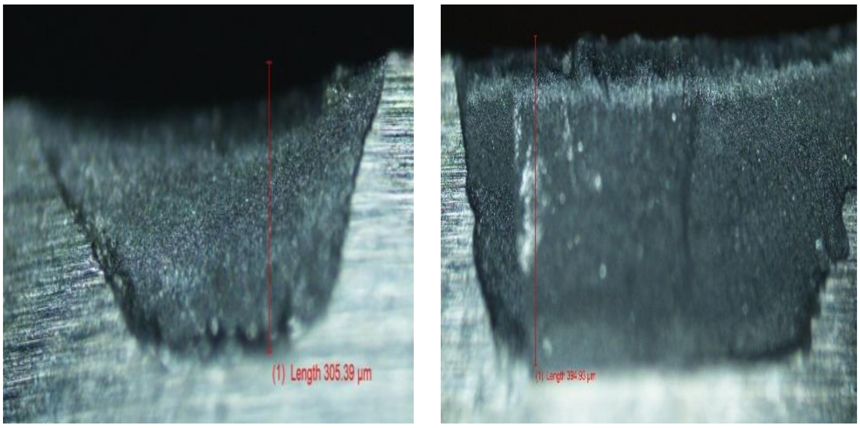
Fig. 2. Tool life against variation of machining parameter: (a) cutting speed, (b) feed rate, (c) axial depth of cut.

Figures 3(a) and (b) exhibits the tool flank wear on the cemented carbide insert under the dry environment at low cutting speed and the rest machining parameters and vice versa, respectively.

It is observed that wear with longest tool life of 16.79 minutes has a good wear pattern than shorter tool life due to the capability of high cutting speed in driving to the reduction of BUL formation on the flank face. Furthermore, apparent tool wear is an existence suddenly consequently the phenomenon of thermal shock on the cutting tool edge.

Table 3 displays the ANOVA results on the cutting tool life under dry machining. It shows clearly that the cutting speed and feed rate have significant effects on the tool life when the selected variables *P*-values are less than 0.05 at 95% confidence level. *P*-values of 0.022 and 0.038 were representing both significant factors.

On the other hand, the other factors and interactions, which are stated in Table 3 are insignificant influence on tool life due to the fact the *P*-value is greater than 0.05.



(a) Longest tool life - length 305.39 μm.

(b) Shortest tool life - 394.93 μm.

Fig. 3. Tool flank wear under dry milling.

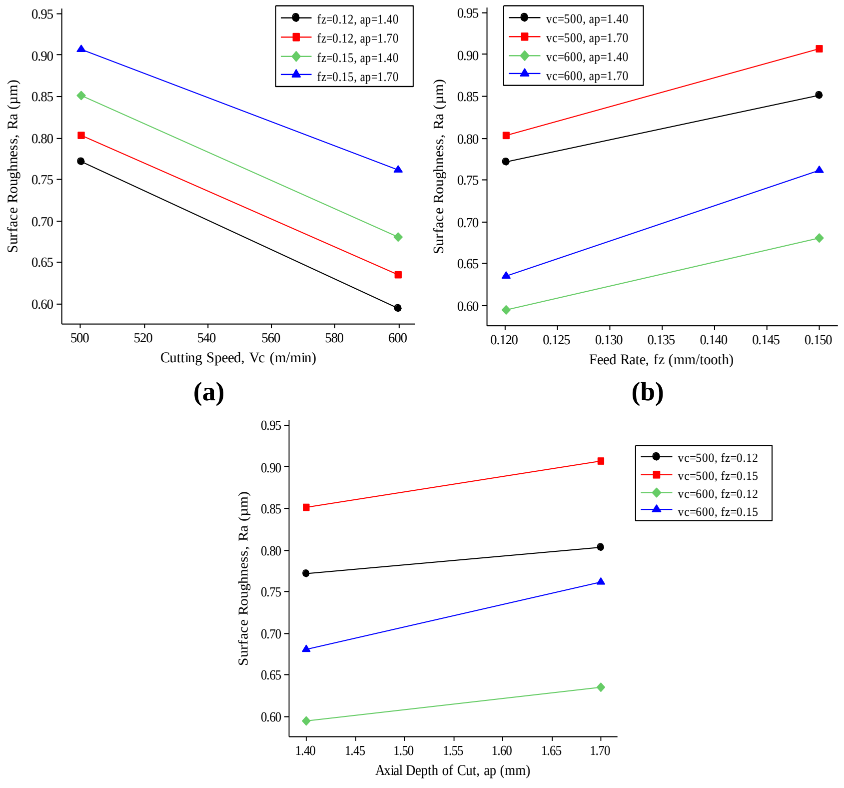
Table 3. ANOVA result for tool life.

Factor	DF	SS	*F*	*P*
Cutting speed, v_c	1	95.981	850.80	0.022
Feed rate, f_z	1	31.800	281.89	0.038
Axial depth of cut, a_p	1	10.374	91.96	0.066
v_c*f_z	1	4.307	38.18	0.102
v_c*a_p	1	0.019	0.17	0.752
f_z*a_p	1	1.088	9.64	0.198
Error	1	0.113		
Total	7	143.682		

The surface roughness of the machined surface was influenced by the machining parameters and environment. Generally, the lower value of Ra is considered as excellent indicators affecting the machined surface. Figures 4(a) to (c) demonstrates the visual results for surface roughness of machined surface with a variation of machining parameter using cemented carbide.

The Ra value may bring down at the elevated cutting speed with low feed rate and axial depth of cut. The cutting with speed of 600 m/min, the feed rate of 0.12 mm/tooth and axial depth of 1.40 mm represent minimum Ra of 0.595 µm whilst the maximum Ra of 0.907 µm was obtained at cutting speed, feed rate, and axial depth of cut, which are 500 m/min, 0.15 mm/tooth and 1.70 mm, respectively.

Obviously, this experiment affirms the fact that a high cutting speed with the low combination of feed rate and axial depth of cut has the potential to promote a favourable solution in the machining process [25]. This similar work also reported by Anwar et al. [26] that the selected high cutting speed and low feed, which are 5000 rpm and 900 mm/min, respectively was significantly effective to yield minimal Ra value. Besides that, the Ra value was found to be lower in between a minute of 4 to 7 than the initial cutting at 600 m/min, 0.12 mm/tooth, and 1.40 mm as exhibited in Fig. 5. This occurs possibly due to the large wear curvature radius and the smooth cutting edge tends to the better roughness.



(a) **(b)**

(c)

Fig. 4. Surface roughness against variation of machining parameter: (a) cutting speed, (b) feed rate, (c) axial depth of cut.

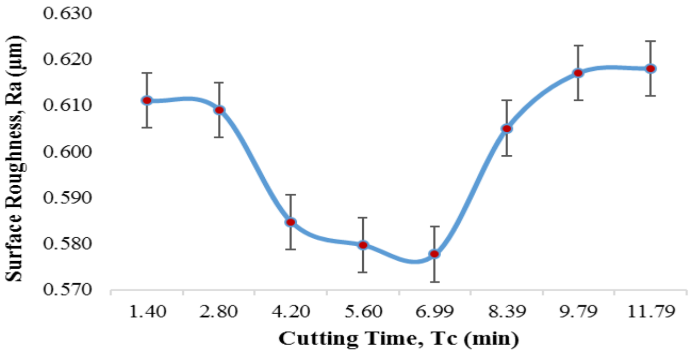


Fig. 5. Trend of surface roughness at v_c: 600 m/min, f_z: 0.12 mm/tooth and a_p: 1.40 mm.

High readings of surface roughness generated in dry machining are possible because of chips sticking to the tool flank face as presented in Fig. 6. This evolution can heighten the friction degree at the tool-workpiece interfaces, which leads to a poor surface finish. At higher feed, the saw tooth chips produced will contribute toward the cycle's variant in the cutting force. This situation could induce a higher vibration rate, which produces drawbacks in cutting tool life and machine surface. ANOVA results on the machined surface roughness under dry machining are exhibited in Table 4. It is evident that the cutting speed and feed rate have significant effects on the surface roughness when the selected variables P-values are less than 0.05 at 95% confidence level. P-values for both significant factors were 0.027 and 0.045. It also shows a great percentage of 68.28% contributed by the cutting speed, followed by 24.33% of the feed rate. In addition, the other factors and interactions, which are presented in Table 4 are insignificant due to the fact the P-value is greater than 0.05.

According to Figs. 2 and 4, extraordinary results for tool lifespan and surface roughness were achieved at speeds of 500 and 600 m/min, respectively, with low combinations of the feed rate of 0.12 mm/tooth and an axial cutting depth of 1.40 mm. This could be due to the occurrence of small friction in the tool-work contact area in reaching the long tool life and high shear pressure between the workpiece and chips to produce good surface roughness.

Fig. 6. Evolution of built-up at cutting speed of 600 m/min.

Table 4. ANOVA result for surface roughness.

Factor	DF	SS	*F*	*P*
Cutting speed, v_c	1	0.054450	555.61	0.027
Feed rate, f_z	1	0.019404	198.01	0.045
Axial depth of cut, a_p	1	0.004901	50.01	0.089
v_c*f_z	1	0.000113	1.15	0.478
v_c*a_p	1	0.000060	0.62	0.576
f_z*a_p	1	0.000722	7.37	0.225
Error	1	0.000098		
Total	7	0.079748		

4. Conclusions

This paper provides an experimental work on the cutting tool life and machined surface roughness of aluminium alloy 7075-T6 involving the selected machining parameters in dry high-speed milling process using the cemented carbide. A recommendation is provided for future work, which is the response surface method (RSM) should be employed so that the trend and the relationship between machining parameters and fluid environment can be observed in the cutting tool life and machined surface roughness. From the results that were presented, the major conclusions are drawn as follows:

- Raise and diminish in cutting speed and low of feed rate and axial depth of cut resulted in a promising performance of tool life and surface roughness, respectively.
- The cutting at speeds of 500 and 600 m/min at the feed rate of 0.12 mm/tooth and axial depth of cut of 1.40 were ascertained to extend the tool life and minimize surface roughness value, respectively.
- From ANOVA results, the cutting speed was found to be the most significant factor, followed by the feed rate that affects cutting tool life and machined surface roughness.
- BUL formation on tool surface is responsible for a decreasing of tool life. A great value in cutting speed and a smaller value of the feed rate and axial depth of cut can inhibit the quicker formation of the BUL on the cutting tool.
- The size of wear curvature has created a huge potential of promoting the smooth machined surface.

Nomenclatures

a_p	Axial depth of cut, mm
f_z	Feed rate, mm/tooth
Ra	Surface roughness, µm
TL	Tool life, min
v_b	Tool flank wear, mm
v_c	Cutting speed, m/min

Abbreviations

ANN	Artificial Neural Networks

ANOVA	Analysis of Variance
BUL	Build-Up Layer
H-DLC	Hydrogenated Diamond-Like Carbon
RSM	Response Surface Method

References

1. Santos, M.C.; Machado, A.R.; Sales, W.F.; Barrozo, M.A.S.; and Ezugwu, E.O. (2016). Machining of aluminium alloys: A review. *International Journal of Advanced Manufacturing Technology*, 86(12), 3067-3080.
2. Saoubi, R.M.; Axinte, D.; Leung, S.; Nobel, C.; Attia, H.; Kappmeyer, G.; Engin, S.; and Sim, W.M. (2015). High performance cutting of advanced aerospace alloys and composite materials. *CIRP Annals - Manufacturing Technology*, 64(2), 557-580.
3. Warren, A.S. (2004). Developments and challenges for aluminium - A boeing perspective. *Materials Forum*, 28, 24-31.
4. Yoshida, H. (2013). Alloy development for transportation in sumitomo light metal. *Proceedings of the 12th International Conference on Aluminium Alloys*. Yokohama, Japan, 54-61.
5. Kumar, S.M.; Pramod, R.; Kumar, M.E.S.; and Govindaraju, H.K. (2014). Evaluation of fracture toughness and mechanical properties of aluminium alloy 7075-T6 with nickel coating. *Proceedings of the 12th Global Congress on Manufacturing and Management*. Vellore, India, 178-185.
6. Subramanian, M.; Sakthivel, M.; Sooryaprakash, K.; and Sudhakaran, R. (2013). Optimization of end mill tool geometry parameters for Al7075-T6 machining operations based on vibration amplitude by response surface methodology. *Measurement: Journal of the International Measurement Confederation*, 46(10), 4005-4022.
7. Isadare, A.D.; Aremo, B.; Adeoye, M.O.; Olawale, O.J.; and Shittu, M.D. (2013). Effect of heat treatment on some mechanical properties of 7075 aluminium alloy. *Materials Research*, 16(1), 190-194.
8. Prasad, N.E.; and Wanhill, R.J.H. (2017). *Aerospace materials and material technologies*. *Volume 1: Aerospace materials*. Singapore: Springer Nature Singapore.
9. Zainol, A.; and Yazid, M.Z.A. (2018). Review of development towards minimum quantity lubrication and high speed machining of aluminium 7075-T6. *Journal of Advanced Manufacturing Technology*. 12(1), 129-142.
10. Martín, M.J.; Cano, M.J.; Castillo, G.; Herrera, M.J.; and Martín, F. (2018). Influence of milling parameters on mechanical properties of AA7075 aluminium under corrosion conditions. *Materials (Basel)*, 11(9), 1-17.
11. Cai, X.J.; Ming, W.W.; and Chen, M. (2012). Surface integrity analysis on high speed end milling of 7075 aluminium alloy. *Advanced Materials Research*, 426, 321-324.
12. Ibrahim, G.A.; Hassan, C.; Haron, C.; Ghani, J.A.; Yasir, A.; Said, M.; and Yazid, M.Z.A. (2011). Performance of PVD-coated carbide tools when turning inconel 718 in dry machining. *Advances in Mechanical Engineering*, 1-7.

13. Najiha, M.S.; Rahman, M.M.; and Yusoff, A.R. (2016). Environmental impacts and hazards associated with metal working fluids and recent advances in the sustainable systems: A review. *Renewable and Sustainable Energy Reviews*, 60, 1008-1031.
14. Amiril, S.A.S.; Rahim, E.A.; and Syahrullail, S. (2017). A review on ionic liquids as sustainable lubricants in manufacturing and engineering: recent research, performance, and applications. *Journal of Cleaner Production*, 168, 1571-1589.
15. Boubekri, N.; and Shaikh, V. (2015). Minimum quantity lubrication (MQL) in machining : benefits and drawbacks. *Journal of Industrial and Intelligent Information*, 3(3), 205-209.
16. Weinert, K.; Inasaki, I.; Sutherland, J.W.; and Wakabayashi, T. (2004). Dry machining and minimum quantity lubrication. *CIRP Annals - Manufacturing Technology*, 53(2), 511-537.
17. Shokrani, A.; Dhokia, V.; and Newman, S.T. (2012). Environmentally conscious machining of difficult-to-machine materials with regard to cutting fluids. *International Journal of Machine Tools and Manufacture*, 57, 83-101.
18. Pattnaik, S.K.; Bhoi, N.K.; Padhi, S.; and Sarangi, S.K. (2017). Dry machining of aluminum for proper selection of cutting tool: tool performance and tool wear. *International. Journal of Advanced Manufacturing Technology*, 98(4), 55-65.
19. Benedicto, E.; Carou, D.; and Rubio, E.M. (2017). Technical, economic, and environmental review of the lubrication/cooling systems used in machining processes. *Procedia Engineering*, 184, 99-116.
20. Jomaa, W.; Songmene, V.; and Bocher, P. (2014). Surface finish and residual stresses induced by orthogonal dry machining of AA7075-T651. *Materials*, 7(3), 1603-1624.
21. Gómez-Parra, A.; Álvarez-Alcón, M.; Salguero, J.; Batista, M.; and Marcos, M. (2013). Analysis of the evolution of the built-up edge and built-up layer formation mechanisms in the dry turning of aeronautical aluminium alloys. *Wear*, 302(2), 1209-1218.
22. Suresh Kannan, I.; and Ghosh, A. (2014). Dry machining of AA7075 by H-DLC coated carbide end mill. *Proceedings of the International Conference on Advances in Manufacturing and Materials Engineering*. Mangalore, India, 2615-2621.
23. Kasim, M.S.; Che Haron, C.H.; Ghani, J.A.; Sulaiman, M.A.; and Yazid, M.Z.A. (2013). Wear mechanism and notch wear location prediction model in ball nose end milling of inconel 718. *Wear*, 302(2), 1171-1179.
24. Khorasani, A.M.; Reza Soleymani Yazdi, M.; and Safizadeh, M.S. (2011). Tool life prediction in face milling machining of 7075 Al by using artificial neural networks (ANN) and taguchi design of experiment (DOE). *International Journal of Engineering and Technology*, 3(1), 30-35.
25. Rawangwong, S.; Chatthong, J.; Boonchouytan, W.; and Burapa, R. (2013). An investigation of optimum cutting conditions in face milling aluminium 7075-T6 using design of experiment. *Proceedings of the 4th International Conference on Applied Operational Research*. Bangkok, Thailand, 125-135.
26. Anwar, R.; Jahanzaib, M.; Asghar, G.; Wasim, A.; and Hussain, S. (2015). Optimization of surface roughness for Al- alloy 7075-T6 in milling process. *Technical Journal*, University of Engineering and Technology (UET) Taxila, Pakistan, 20(2), 153-159.