Effect of Minimum Quantity Lubrication and Dry Cutting on the Tool Life and Chip Morphology after Milling of Aluminum Alloy 7075-T6

Azreen Zainol, M.Z.A. Yazid

Abstract*: This research deals the experimental works on the effect of minimum quantity lubrication (MQL) and dry cutting towards the cutting tool life and chip morphology in high-speed milling of aluminum alloy 7075-T6 with uncoated carbide tools. MQL and dry cutting were eco-friendly approaches that highlight essential issues in the field of manufacturing technology. Thus, further investigation required to observe the intensity of those approaches. The experiment was done on computer numerical control (CNC) five axes milling machine at distinct machining parameters, which are cutting speed (500 and 600 m/min), feed rate (0.12 and 0.15 mm/tooth) and axial depth of cut (1.4 and 1.7 mm), while the radial depth of cut restricted to 7 mm. The effect of fluid approaches and machining parameters on eight samples have analyzed the result of the setting of three factors and two levels in accordance with the full factorial design and analyzed further using ANOVA. The MQL flow rate was set at 100 mL/h. The tool life criterion was determined when the tool wear failure reached 0.30 mm. The chips collected from all machining conditions were taken to be examined using an optical microscope. The empirical model of tool life for the MQL and dry cutting has been developed within the experimental ranges evaluated. The prolonged tool lifespan beyond 20.14 minutes and favorable chip formation were obtained at 500 and 600 m/min, 0.12 mm/tooth, and 1.40 mm, respectively under MQL 100 mL/h. MQL 100 mL/h appeared to be one fit for metal cutting industry that prioritizes clean and green machining as well as the use of appropriate machining parameters as it leads to economic benefits in terms of fluid cost-saving and the better machinability.

***Index Terms*: Minimum Quantity Lubrication, Dry Cutting, Tool Life, Chip Morphology.**

I. INTRODUCTION

The cutting fluid in the metal cutting process apparent provides a tremendous impact on the performance of the tool and chip flow, particularly the generation of longer tool life and improved chip removal [1], [2]. However, for the case of a great performance generation, it has to involve high cutting speed, thus resulting in the poor machinability of the product. It also tends to a high-risk threat towards the environment and workers' health. Boubekri and Shaikh [3] reported that are between 7.5% and 17% of the total manufacturing cost are cutting fluid and its management costs compared to cutting tools which is only 4%. Due to these issues, some alternatives have been found in enhancing considerably the performance of machinability as well as safer environmental. Minimum quantity lubrication (MQL) and dry cutting were regarded as a significance cutting fluid approaches due to their nature of environmentally friendly and viable economic.

MQL is an approach which sprays the cutting fluid in a small amount in the range of 10 to 100 mL/h into the cutting zone with the assisted by compressed air while the dry cutting in relation to the cutting process without the cutting fluids [4]-[6]. The dry cutting was practicable in the various cutting process, but it may potential leads to a reduction of cutting tool life and machined surface quality as well as poor chip flow. It has been found that MQL is possible to maintain or improve reasonable tool life and surface quality. There are some prior studies have confirmed that MQL ensures satisfactory results in practical cutting processes and that it can enable superior performance obtained [7], [8]. MQL stimulates better overall performance than dry cutting in which it suits employed in high-speed machining for eco-friendly materials, including aluminum alloy and magnesium using carbide tools [1]. It due to MQL could reach deep into tool face and the work piece [9]. Despite the advantages of MQL, it is susceptible to produce wet dust and smoke beside be in need of an additional tool [10]. Consequently, dry cutting has the ability to be a competitive alternative in certain situations that emphasize clean machining. Aluminum alloy 7075-T6 is a light structural material that versatile and economical in the 7000 series where cutting fluid required in retaining its superiority in various of the cutting process. It possesses remarkable characteristics preferred in improving the strength of structural components of aerospace industry such as moderate hardness, average machinability, moderate toughness, heat treatable, high tensile strength, and high corrosion resistance [11]. In addition, the foregoing studies associated with the effect of MQL and dry cutting on the tool life and chip morphology are necessary in order to attain the goal of machining.

Revised Manuscript Received on 30 July 2019.
* Correspondence Author
Azreen Zainol*, Manufacturing Section, Universiti Kuala Lumpur-Malaysia Italy Design Institute, Kuala Lumpur, Malaysia.
M.Z.A. Yazid, Manufacturing Section, Universiti Kuala Lumpur-Malaysia Italy Design Institute, Kuala Lumpur, Malaysia.

Kouam et al. [12] analyses the impact of minimum quantity lubrication (MQL) with a flow rate of 1.75 and 3 mL/min and dry cutting in turning of the aluminum alloy 7075-T6. The chip formation was selected as the dependent variables. It was observed that MQL with a flow rate of 3 mL/min shows more long chips than a flow rate of 1.75 mL/min and dry cutting. They revealed that an effective approach was MQL with a flow rate of 1.75 mL/min. Khorasani et al. [13] study the interaction of machining parameters, namely spindle speed, feed rate, and depth of cut on tool life and demonstrate the capability of Artificial Neural Networks (ANN) in order to predict and modeling tool life. ANN is referred to as a computational model constituted of the functions of biological neural networks. They conducted the study on a milling machine using the end mill with 4 flutes towards the work piece of aluminum alloy 7075-T6. The elected machining parameters were 95, 360, 565, 950 and 1500 rpm, 22, 98, 132, 200, and 360 mm/min and 0.2, 0.4, 0.6, 0.8, and 1.0 mm for spindle speed, feed rate, and depth of cut, respectively. The result shows that the longest tool life of 554 min obtained at a spindle speed of 360 rpm, the feed rate of 22 mm/min and depth of cut of 0.4 mm during the milling process whilst 582.8904 min was the tool life predicted by ANN. They concluded that the lowest feed rate tends to the longest tool life. Fang et al. [14] make an experimental to analysis the effect of cutting conditions and tool geometry on the serrated chip geometry in high-speed machining of milling of aluminum alloy 7075-T6. The mathematical model was employed in the experimental for validation purpose. The parameters involved are cutting speed, vc of 1000 to 5000 m/min, tool rake angle, $\gamma 1$ of -10 to 10 degrees and undeformed chip thickness, hc of 0.05 to 0.25 mm. The result shows that the pitch of the serrated chip, p increases when decreasing cutting speed, vc, tool rake angle, $\gamma 1$ and increasing undeformed chip thickness, hc. Nevertheless, they concluded that there no significant interaction effects among the cutting speed, the tool rake and the undeformed chip thickness on chip formation. In the present paper, an experimental study was carried out on the performance of MQL and dry milling of aluminum alloy 7075-T6 with uncoated carbide tools at high-speed cutting towards tool life and chip morphology. The effects of machining parameters were investigated.

II. METHODOLOGY

The experimental works were carried out on the five axes milling machine DECKEL MAHO DMU 50 eVolution with computer numerical control (CNC) Heidenhain ITNC 530 with the maximum spindle speed of 16000 rpm and feed rate of 20000 mm/min. Aluminum alloy 7075-T6 with the dimension of the length of 300 mm, the width of 150 mm and a thickness of 40 mm was selected as work piece material. This material possesses the chemical composition of 90.3% Al, 5.6% Zn, 2.5% Mg, and 1.6% Cu. The tools employed were QPMT 10T335PPEN uncoated carbide insert with a diameter of 10 mm. It was mounted on a 14 mm nominal diameter single flute SUMITOMO tool holder WRC10016ES. The tool overhang of 50 mm was maintained throughout the experiment to avoid deflection and vibration. A work piece block underwent a face milling of 1 mm to remove any surface irregularities that could affect the machining result. The involved machining parameters include cutting speed (vc), feed rate (fz), and axial depth of cut (ap) as shown in Table 1 in while the step-over (ae) kept constant to 7 mm. The MQL machine mounted on the outer wall of the CNC machine and flow rate was set at 100 mL/h.

The tool life criterion was assessed when reached tool failure, which is the flank wear (vb) of 0.30 mm according to ISO 8688-2-1989 [15]. Tool flank wear and chips collected from all machining conditions were examined using an optical microscope Olympus BX53M. Eight runs were designed as a result of a combination of three different controlled factors and two levels adopted the full factorial design. Subsequently, the analysis of variance (ANOVA) used to determine the machining parameters most influence tool life. The empirical model of tool life for the MQL and dry cutting has been developed with adequate accuracy within the experimental ranges.

Table 1: Machining Parameter for milling tests

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

III. RESULTS AND DISCUSSION

Figure 1 presents the effect of the fluid application on the cutting tool life for MQL 100 mL/h and dry cutting in each machining parameters. It can be seen that the lifespan between about 3.36 and 20.14 minutes was taken. The longest tool life of 20.14 minutes was achieved at cutting speed of 500 m/min, the feed rate of 0.12 mm/tooth, and axial depth of cut of 1.40 mm under micro-lubrication. Shortest tool life was 3.36 minutes at the elevated combination of cutting speed, feed rate, and axial depth of cut which are 600 m/min, 0.15 mm/tooth, and 1.70 mm, respectively under the dry cutting. As illustrated in Figure 1, the higher tool life was obtained as MQL was applied. It is evident that the 500 m/min in cutting speed contributes to the higher column, which shows the longest tool life is obtained when MQL 100 mL/h was utilized. At 600 m/min, the column seems low which indirectly clearly show up the progress of tool life is decreasing as well as influenced by other inputs, mainly feed rate and axial depth of cut. This occurred because they involve movement and then determine the thermal effect and also friction force between tool-work interfaces. Table 2 displays the analysis of variance (ANOVA) table on the cutting tool life under MQL mL/h and dry cutting. It was found that the cutting speed and feed rate have significant effects on the tool life for both approaches when the selected variables P-values are less than 0.05. P-values for both significant factors were 0.021 and 0.036 in MQL 100 mL/h whilst 0.022 and 0.038 in dry cutting. In addition, the other factors and interactions which are stated in Table 2 are insignificant due to the fact the P-value is greater than 0.05.

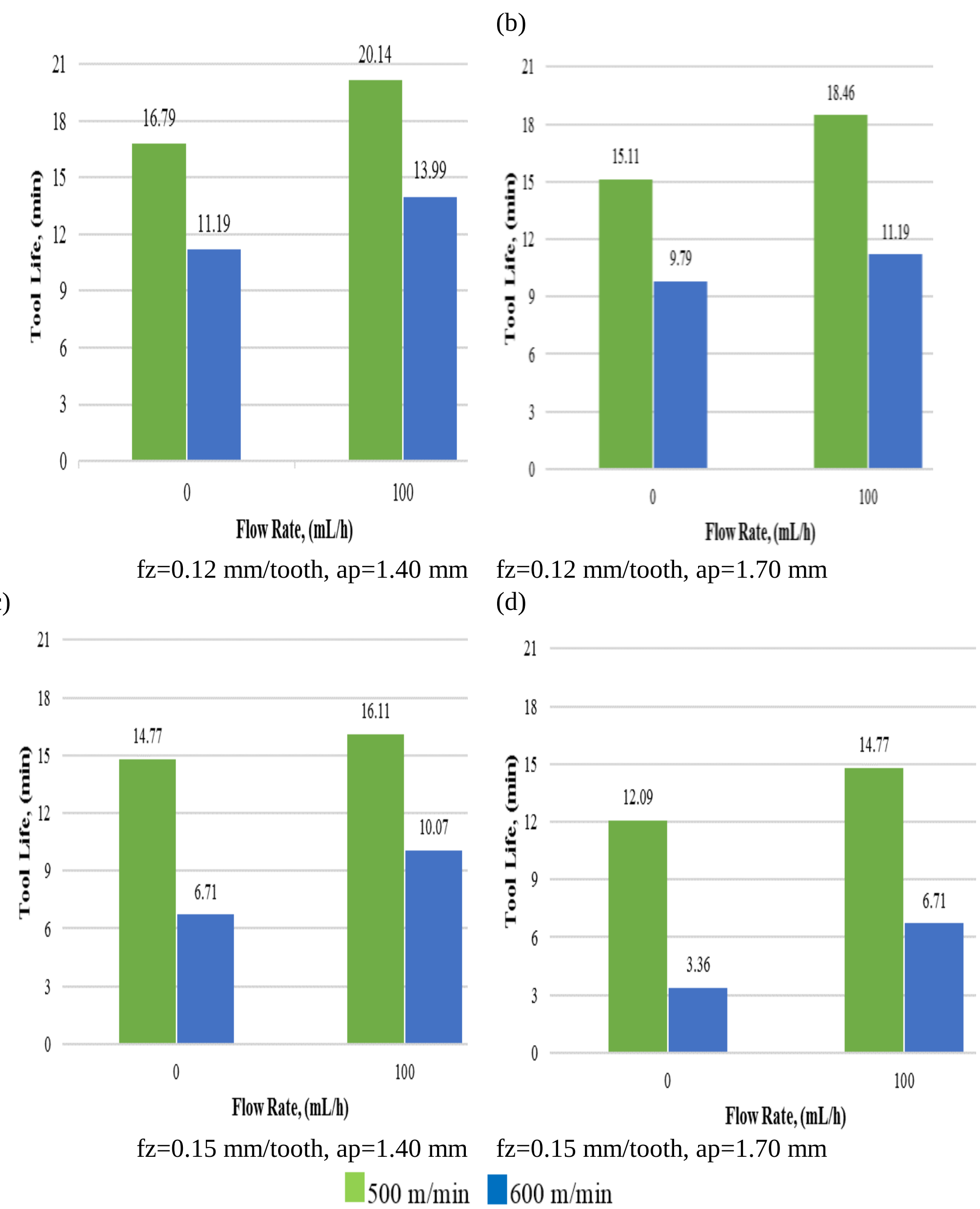


Figure 1: Effect of Fluid Application on Tool Life

R^2 adj of 99.49% and 99.45% proved that the model is feasible and outstanding for the prediction model of uncoated carbide tools in the MQL 100 mL/h and dry cutting, respectively.

(a)

Table 2: ANOVA for Tool Life under MQL 100 mL/h and Dry Cutting

Source	DF	SS		F		P	
		MQL	Dry	MQL	Dry	MQL	Dry
Cutting Speed, vc	1	94.669	95.981	935	850.8	0.021	0.022
Feed Rate, fz	1	32.482	31.8	320.81	281.89	0.036	0.038

Axial Depth of Cut, ap	1	10.534	10.374	104.04	91.96	0.062	0.066
vc*fz	1	0.058	4.307	0.57	38.18	0.588	0.102
vc*ap	1	1.232	0.019	12.17	0.17	0.178	0.752
fz*ap	1	0.006	1.088	0.06	9.64	0.847	0.198
Error	1	0.101	0.113				
Total	7	139.082	143.682				

MQL 100 mL/h: S= 0.3182 R^2= 99.93% R^2 (adj)= 99.49%

Dry Cutting: S= 0.3359 R^2= 99.92% R^2 (adj)= 99.45%

An empirical model able generated to boost the database of high-speed milling of aluminum alloy 7075-T6. It uses relationships between the fluid approach and machining parameters to predict cutting tool life. Thus, the model of uncoated carbide tools can be developed using the basic formula as follows:

$$y = \beta 0 + \beta 1x1 + \beta 2x2 + \beta 3x3 \quad (1)$$

Then, equation (1) may be transformed into the model of tool life in the natural form. The empirical model of the tool life under MQL and dry cutting is expressed like equations (2) and (3), respectively.

$$T_L = -53.8987 + 0.0688vc + 134.3199fz + 7.6424ap \quad (2)$$

$$T_L = -56.5815 + 0.06927vc + 132.9fz + 7.5844ap \quad (3)$$

T_L denoting tool life which referred to the total cutting time when the tool reached failure. From equations (2) and (3), the value of the tool life can be calculated directly by substitute values vc = 500 m/min, fz = 0.12 mm/tooth, and ap = 1.40 mm. The tool lifespan calculated for MQL and dry cutting is equivalent to respective 7.32 and 4.62 minutes.

Chip morphology can be described from various chip parameters, in which one of them is the chip formation. The chips formed have different shapes and sizes depending on the selection of machining conditions that are carried out. Figure 2 depicts the evolution of chip macro at two different combinations of machining parameters under MQL 100 mL/h and dry cutting when milled of aluminum alloy 7075-T6 using uncoated carbide tools. The feed rate value was taken into account as a secondary factor of the machining condition that plays a crucial role in determining the chip's behavior obtained [16]. The results have found a chip helical form in this study.

According to Figure 2, it was observed that chip debris obtained in both machining conditions of MQL 100 mL/h and dry cutting was the serrated chip with silver color. Color chips brighter indicate lower temperatures [17]. It seems clear that smaller chip with more helical was attained in MQL 100 mL/h with the highest value in cutting speed of 600 m/min and low value of feed rate of 0.12 mm/tooth, whereas the biggest chip was attained in the dry cutting with the lowest value in cutting speed and highest value in feed rate and depth of cut. A smaller chip with more helical was allowing the tool to reduce the formation of built-up edge, indirectly assists the reduced deterioration of the tool. The big chip typically refers to the high value of the depth of cut employed throughout the machining. The addition of depth of cut has beneficial potential in increasing the material removal rate (MRR), thus heighten the productivity in terms of machining efficiency. However, it presents the drawback to low tool lifespan due to the degree of temperature is increased, thus resulting in the rise thermal stress on the tool flank face.

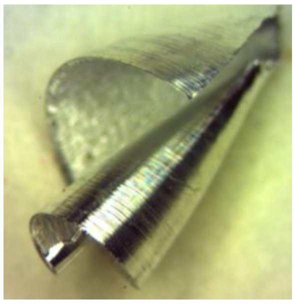
Figure 3 displays the behavior chip surface on the back surface at a different feed rate with a cutting speed of 600 m/min. It was observed that the back surface was smooth and flat under MQL 100 mL/h at the initial cutting for both feed rates in comparison to dry cutting. As the feed rate increased from 0.12 to 0.15 mm/tooth, jagged and rough appearance gradually occurred after breaking at the medium and final cutting, particularly in the dry cutting. This occurred due to the shear instability and high frictional degree as a result of a nearly worn-out cutting tool edge. Therefore, with the application of MQL, it could decrease severe heat localization, which tends to destroy the cutting tool edge.

I. CONCLUSION

This research work concluded that MQL 100 mL/h at a low combination of machining parameters could lengthen the tool lifespan than dry cutting. The tool life significantly increases by 55%. The empirical model of tool life has been developed for MQL 100 mL/h and dry cutting to predict cutting tool life before the experiment is carried out. Chip produced from both fluid approaches was a serrated chip

with helical form. As the cutting speed increases and feed rate decreases, there was a good change in the chip formation. In this regard, the chip morphology was nearly not relying on cutting speed, but closely related to the feed rate.

Machining Parameter	MQL 100 mL/h	Dry Cutting

vc= 600 m/min;
fz= 0.12 mm/tooth;
ap= 1.40 mm
		

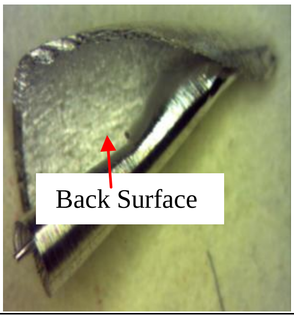
vc= 500 m/min;
fz= 0.15 mm/tooth;
ap= 1.70 mm
		

Figure 2: Chip Macro at at Two Variation of Combinations of Machining Parameters under MQL 100 mL/h and Dry Cutting

ACKNOWLEDGMENT

The authors would like to thank Universiti Kuala Lumpur Short-Term Research Grant (STR 15051) for the funding to carry out this research work.

REFERENCES

1. M. H. S. Elmunafi, M. Y. Noordin, and D. Kurniawan, "Tool Life of Coated Carbide Cutting Tool when Turning Hardened Stainless Steel under Minimum Quantity Lubricant Using Castor Oil," *Procedia Manufacturing*, vol. 2, no. 2, pp. 563–567, 2015.
2. C. A. Schuch Bork, J. F. Souza Gonçalves, and J. O. Gomes, "The Jatropha curcas vegetable base soluble cutting oil as a renewable source in the machining of aluminum alloy 7050-T7451," *Industrial Lubrication and Tribology*, vol. 67, no. 2, pp. 181–195, 2015.
3. N. Boubekri and V. Shaikh, "Minimum Quantity Lubrication (MQL) in Machining : Benefits and Drawbacks," *Journal of Industrial and Intelligent Information.*, vol. 3, no. 3, pp. 205–209, 2015.
4. Chetan, S. Ghosh, and P. V. Rao, "Application of sustainable techniques in metal cutting for enhanced machinability: a review," *Journal of Cleaner Production*, vol. 100, pp. 17–34, 2015.
5. S. Debnath, M. M. Reddy, and Q. S. Yi, "Environmental friendly cutting fluids and cooling techniques in machining: A review," *Journal of Cleaner Production*, vol. 83, pp. 1–38, 2014.
6. A. Zainol and M. Z. . Yazid, "The effect of portable MQL applicator onto carbide insert during turning Inconel 718," *Journal of Mechanical Engineering and Sciences*, vol. 12, no. 2, pp. 3605–3613, 2018.
7. P. C. Priarone, M. Robiglio, L. Settineri, and V. Tebaldo, "Milling and turning of titanium aluminides by using minimum quantity lubrication," *Procedia CIRP*, vol. 24, pp. 62–67, 2014.
8. F. Zhou, H. Zhang, J. W. Sutherland, Z. Jiang, and Y. Wang, "Optimization of machining parameters considering minimum cutting fluid consumption," *Journal of Cleaner Production*, vol. 108, pp. 183–191, 2015.
9. S. A. Lawal, I. A. Choudhury, and Y. Nukman, "A critical assessment of lubrication techniques in machining processes: A case for minimum quantity lubrication using vegetable oil-based lubricant," *Journal of Cleaner Production.*, vol. 41, pp. 210–221, 2013.
10. R. Khettabi, M. Nouioua, A. Djebara, and V. Songmene, "Effect of MQL and dry processes on the particle emission and part quality during milling of aluminum alloys," *International Journal of Advanced Manufacturing Technology*, vol. 92, no. 8, pp. 2593–2598, 2017.
11. M. Subramanian, M. Sakthivel, K. Sooryaprakash, and R. Sudhakaran, "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*, vol. 46, no. 10, pp. 4005–4022, 2013.
12. J. Kouam, V. Songmene, M. Balazinski, and P. Hendrick, "Effects of minimum quantity lubricating (MQL) conditions on machining of 7075-T6 aluminum alloy," *International Journal of Advanced Manufacturing Technology*, vol. 79, no. 8, pp. 1325–1334, 2015.
13. A. M. Khorasani, M. Reza Soleymani Yazdi, and M. S. Safizadeh, "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*, vol. 3, no. 1, pp. 30–35, 2011.
14. N. Fang, J. Yang, and N. Liu, "Analytical Predictive Modeling of Serrated Chip Formation," *Mechanical Engineering*, pp. 1–9, 2004.
15. J. A. Ghani, C. H. Che Haron, M. S. Kasim, M. A. Sulaiman, and S. H. Tomadi, "Wear mechanism of coated and uncoated carbide cutting tool in machining process," *Journal of Materials Research*, vol. 31, no. 13, pp. 1873–1879, 2016.
16. S. Imbrogno, S. Rinaldi, A. G. Suarez, P. J. Arrazola, and D. Umbrello, "High speed machinability of the aerospace alloy AA7075 T6 under different cooling conditions," *Proceedings of the 21st International ESAFORM Conference on Material Forming*, vol. 1960, pp. 1–7, 2018.
17. Yazid, M. Z. A. (2014). *Kebolehmesinan Inconel 718 Pada Pemesinan Laju Tinggi Dalam Keadaan Kuantiti Pelincir Minima*. Universiti Kebangsaan Malaysia, Bangi, Malaysia.

AUTHORS PROFILE

Azreen Zainol Currently pursuing Master of Engineering Technology (Manufacturing) in Universiti Kuala Lumpur-Malaysia Italy Design Institute, Kuala Lumpur, Malaysia. He graduated from Universiti Kuala Lumpur-Institute of Product Design and Manufacturing in Bachelor of Engineering Technology in Manufacturing Systems in 2014. His research mainly focuses in Metal Cutting, Cutting Tools, and Fluid Techniques. He is performing research to develop sustainable machining processes, which are environmentally friendly and harmless to the machining operators.

M.Z.A. Yazid Associate Professor in Manufacturing Section at Universiti Kuala Lumpur-Malaysia Italy Design Institute, Kuala Lumpur, Malaysia. He was awarded Ph.D. in Mechanical and Materials Engineering from Universiti Kebangsaan Malaysia, Selangor, Malaysia. He received his Master of Science in Engineering Business Management from University of Warwick, United Kingdom. His areas of interest are Mechanical Properties, Corrosion, Machining, and Materials. A recent publication is "The effect of portable MQL applicator onto carbide insert during turning Inconel 718".

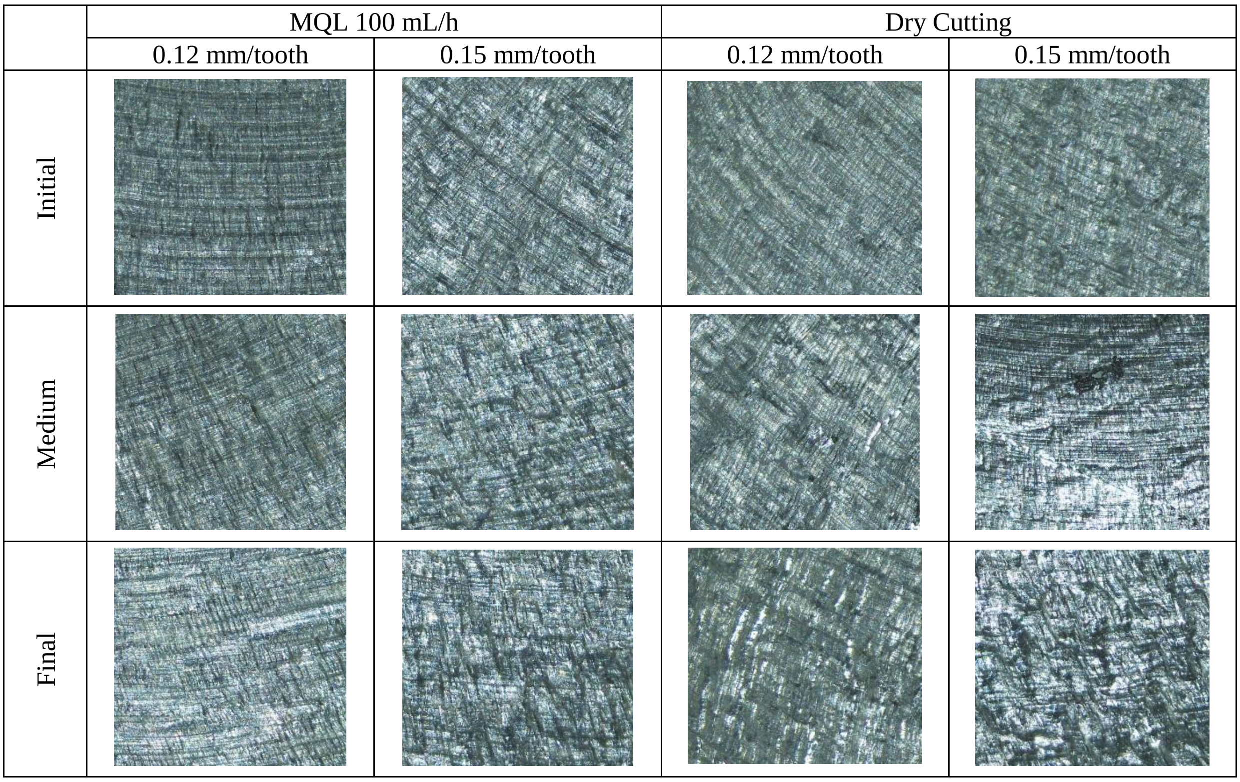


Figure 3: The Behavior Chip Surface on the Back Surface at vc = 600 m/min