International Journal of Engineering & Technology, 8 (1.1) (2019) 80-88

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Experimental Study on the Degree of Surface Generation by Edge Preparation Tools in Milling 316L

Rino Andias[1], Rasidi Ibrahim[2], Chong Yee Long[3], Chee Yung Ng[2], Noor Hakim[2], M. Sukri Mustapa[2]

[1] Fakulti Rekayasa Industri, Telkom University, Bandung Indonesia
[2] Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia
[2]R & D Center, HPMT Industries Sdn Bhd, Shah Alam, Selangor Darul Ehsan, Malaysia
**Corresponding Author Email: Rasidi@uthm.edu.my*

Abstract

Milling is one of the most common machining methods in the industry today to produce the desire shape from raw workpiece. Improvement of milling performance is always the simplest way to reduce the production cost and increase the product's quality. Since cutting tool is the basic requirement of a milling process, the study on structure of cutting tool especially the cutting edge is a breakthrough point to enhance the milling performance. Geometry of cutting edge of uncoated endmill with diameter of 6mm had been modified through edge preparation process in this study. The cutting radius had been enlarged and the roughness on cutting edge is smoother after the preparation process. The second method to improve milling performance in this study is utilization of cutting fluid. Besides conventional flood cutting, Minimal Quantity Lubrication (MQL) is another method to provide lubrication and reduce cutting temperature by coolant in "mist" form. In this study, both cutting edge preparation and MQL methods are applied in side milling as well as slot milling. The chosen material for the workpiece was stainless steel, a metal with non-magnetic and high corrosion resistance characteristics. The milling performance was evaluated by cutting force and machined surface roughness, which are measured by dynamometer and roughness tester respectively. The lowest cutting force with 93.23N as well as lowest side surface roughness of 0.42µm in slot milling was observed under MQL condition with edge prepared tool.

Keywords: *Cutting edge preparation, cutting tool geometry, drag finishing, MQL, side milling, slot milling.*

1. Introduction

In milling, cutting tool usually rotates in very high speed so that the unwanted material can be removed by the sharp edge (teeth) of the tool. Direction of feed and direction of tool rotation are important considerations in milling process to produce high quality machining surface [1]. Machining parameter such as spindle speed, feed rate, and depth of cut always variance according to the material of the workpiece to be cut to enhance the milling performance [2].
SS316L is a metal alloy with high corrosion resistance, high heat resistance, and non- magnetic characteristic that widely used in medical implants, food industrial, chemical equipment, and knee & hip replacement [3]. However, high temperature during machining may change the mechanical properties or microstructure of the material. Surface roughness as well as dimensional accuracy of manufacturing of the product by this material can directly affects the health of patients. Thus, a lot of considerations taken during the processing of this material.
Beside of machining parameters, changes of cutting edge geometries was investigated as another way to improve machining performance in terms of cutting force and cutting temperature as well [4][5][6][7][8]. Tool horning, also called drag finishing, is a cutting edge preparation method on tools to remove the sharp edge on cutting edge which is a disadvantage on its structure as well as produce a smoother rake and flank face on the tools [9].
Another method to increase the machining performance is application of coolant. Coolant is the fluid with high heat transfer rate that helps to reduce cutting temperature during machining. Besides, coolant also acts as lubricant to reduce the friction between cutting tool and workpiece [10].
Minimum quantity lubrication (MQL) is new technique in method to use coolant during cutting. The main concept of MQL system is to form a very thin layer of lubricant on the surface of cutting tool rather than flood cooling system to cooling down the cutting process [11]. High friction reduction can be achieved through the thin layer of lubricant in order to prevent large heat generation during cutting [12][13][14]. Since the lubricant used in MQL system used only minimum quantity of lubricant which is sufficient for the cutting process, the waste due to exceed coolant usage can be minimized as well as cost saving. Sprayed lubricant by MQL system evaporated immediately therefore the workpiece and machine table can maintain dry throughout the cutting operation.

2. Literature Review

The milling performance can be said strongly depends on cutting parameters and cutting tool. There are found that many researches conducted nowadays on cutting parameters and cutting tool to enhance the milling performance. The influence on machining force by process parameter was investigated [15]. The cutting force of CFRP and GFRP in slot milling is measured in three orthogonal components and recorded by a milling tool dynamometer shows that increased in cutting speed resulted increased in cutting force. The optimal milling operation in the study to be investigated and concluded with low feed rate and high speed.
Cutting force coefficient measured show significant difference with various geometries of cutting edges[16]. The statement was supported with end-mill slotting experiment by cutter with various clearance angle, rake angle, and helix angle. In the comparison of experimental results, the cutter with higher helix angle shows higher average increasing of both radial and tangential cutting force coefficient. According to this statement, the cutting force in an end-milling process increase faster by cutter with higher helix angle due to tool wear. In slot milling process for 42CrMo4 steel, the tool wear and surface integrity has been found influenced significantly by the form factor, which is the ratio of cutting edge segment on rake face to cutting edge segment on flank face [17].
Since the perfectly sharp cutting edge is impossible to produce, there is a defined radius on every cutting edge. The effects on tool life, machined surface, and cutting force by the cutting edge radius are investigated by using ferrite-martensite stainless steel as the experiment workpiece [8]. In the experiment study, inserts with wiper geometry are used and edge prepared with different edge radius. During tool wear test, inserts with edge radius of 15µm performs better than inserts with edge radius of 10µm and 5µm, while the wearing of inserts with edge radius 5µm and 10µm is in chipping edge form, but the wearing of inserts with edge radius of 15µm is in uniform wear. From above statement, insert with larger edge radius is believed has higher strength and wear resistivity.
Beside tool wear, surface roughness of machined surface as well as cutting force of inserts with edge radius of 15µm also display lower value than inserts with edge radius of 10µm and 5µm. This is very interesting statement because sharp cutting edge with smaller radius should have stronger penetration ability into workpiece and generate lower cutting force. In fact, the claim is right only if there is no wearing occurs on the cutting edge. However, the cutting edge with smaller radius (sharper) has lower wear resistance compare to cutting edge with larger edge radius. As shown in Figure 2.7, larger cutting edge radius can be produced through cutting edge preparation, and lower roughness on the prepared cutting edge is observed. From the experiment, micro-defects and burr formation are found on the tool cutting edge with edge radius of 5µm and 10µm while no any defects and burr found on that with edge radius of 15µm at the end of experiment. Furthermore, higher wear of cutting edge leads to produce a poorer roughness of machined surface, the roughness value of machined surface increased as the wear resistivity of cutting edge decreased. In other words, the mechanical strength on cutting edge of insert tools can be improved by produce a larger edge radius through edge preparation. The Figure 1 shows the comparison of cutting edge between with and without preparation [8].

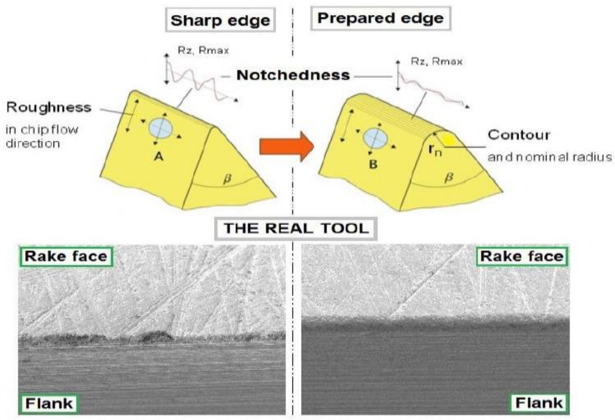

Figure 1: comparison of cutting edge between with and without preparation

Besides the edge radius, cutting mechanism can be enhanced as well by produce a smoother rake surface on cutting edge through edge preparation process. Cutting edge of machining tools are usually fabricated by grinding process which is difficult to produce regular geometry. This leads to reduce the tool life due to chipping on cutting edge and low effective of coating [18]. Changes in rake face roughness and surface textures are found in tools with cutting edge preparation, such as drag finishing and polished with abrasive particle, help to remove the bad surface on rake face, while the changes in rake face are shown in. As a result, smoother surface can be produced since the irregular surface are polished to reduce their roughness. Tools with sharp edge (non-edge prepared) are observed rougher rake face compare to edge prepared tools than edge prepared tools [19]. In other words, Poor rake face on cutting edge leads to high cutting force and cutting temperature due to high friction coefficient. Hole wall with lesser roughness drilled by the tool under edge preparation since rough tool rake face cause chip flow difficulty. While the rake faces of the tools under different edge preparation process which are drag finishing (DF), polishing (POL), and unprepared (SH) were observed under microscope and shown in Figure 2.

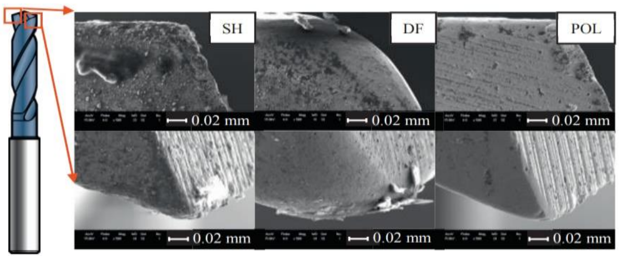

Figure 2: rake face of cutting tools under different edge preparation

Application of cutting fluid is the most common method used during machining to increase the tool life. Tool wear normally increased as the feed rate, cutting speed and depth of cut increased, but lesser tool wear observed by applying cutting fluid [20]. Surface roughness as well as tool life are the most important aspect in metal cutting. Flank wear of a cutting tool is influenced the most by depth of cut and cutting speed. While cutting speed followed by feed rate are the most significant influences toward surface roughness. Cutting temperature was found reduced significantly by the used of cutting fluids so that the tool life improved. Formed chips are able to be flushed by flowing fluids tends to avoid the generation of high heat energy. Coolant used also act as lubricant to reduce the coefficient of friction between the rake face of the tool and chips [21].

Minimal Quantity Lubricant (MQL), is a utilize of cutting fluid in state of mist. Very small volume of cutting oil was transmitted to the cutting area by high air pressure in MQL cooling system. By using 17-4 PH stainless steel as the machining workpiece, the machining performance according to different cooling system was investigated in terms of cutting force and surface roughness [10]. Cryogenic coolant was found with excellent performance in that particular machining process, but it was not the scope in this study. Flank wear of inert tools was found much lesser compare to wet machining and dry machining. There is also lower cutting force measured by MQL machining than the machining without cooing and lubrication. According to the experiment result, 17% of cutting force reduced through MQL system means lesser power consumption that leads to energy savings benefit. Another deduction can be made from the experiment was that the position of nozzle does not significant influence the cutting force [12]. Another machining experiment was carried out by using a difficult-to-cut material, Incoloy 800, with comparison of cutting condition of dry cutting, flood cutting, and MQL cutting. Taguchi method is used on the cutting parameters in the experiment. In both tool wear test and surface roughness test, MQL was generally performs much better than dry cutting and flood cutting in turning of this material [14].

Beside tool cutting edge preparation and MQL, by apply ultrasonic vibration, which with very high frequency and very low amplitude, on either cutting tool or workpiece, the performance of machining can be influenced [22]. Ultrasonic vibration assisted milling (UVAM) had been investigated have different and more complex tool trajectory was modelled with MATLAB [23]. Since the tool was cutting under ultrasonic vibration, the tool tip was moved with the motion combined by the direction of spindle rotation as well as amplitude direction. The tool tip was not contacted to the workpiece at all the time in the cutting and a gap produced between tool tip and the workpiece when the vibration taking them apart [24]. Therefore, the heat generated from the cutting can be dissipated effectively so that longer tool life can be achieved due to lower cutting temperature. As a result, the generally machining performance, such as bur formation can be further enhanced by application of ultrasonic vibration [25].

In this study, machining performance of stainless steel 316L in terms of cutting force and machined surface's roughness was investigated to be increased by combination of cutting edge preparation method and utilization MQL, an environmentally-friendly coolant [26] method.

3. Experiment Setup

In this study, slot milling and side milling are conducted to evaluate the performance of cutting tools between with and without edge preparation. The cutting processes are operated by using the CNC vertical machining center MAZAK NEXUS 410A-II. Since the cutting force is one of the factors to evaluate the result, Dynamometer KISTLER 9254 was used to measure the cutting force in three directional components. While surface roughness tester Mitutoyo SJ400 was used to measure the roughness of machined surfaces.

3.1 Workpiece setup

A stainless steel 316L block with dimension of 150mm x 50mm x 12mm was used as workpiece in this study. In order to measure the cutting force, the workpiece was cut on a dynamometer which clamped on the machine work bench as shown in Figure 3.

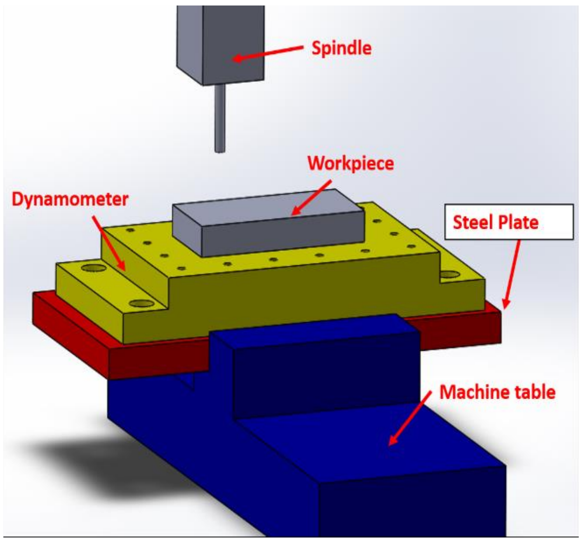

Figure 3: Workpiece setup

3.1 Machining parameter

In this study, 4 difference machining operation will be conducted, which includes 3 side millings, and one slot milling, the cutting parameters of each of the machining operation are shown in Table 1, where Ap, Ae, Vc, Fz, S, and F represent axial depth of cut, radial depth of cut, cutting speed, feed per tooth, spindle speed, and feed rate respectively.

Table 1: Cutting parameter

	Side milling (standard)	Side milling (roughing)	Side milling (finishing)	Slot milling
Ap (mm)	3.0	3.0	3.0	1.8
Ae (mm)	1.8	2.0	0.2	6.0
Vc (m/min)	50	45	70	50
Fz (mm/z)	0.0016	0.011	0.008	0.009
S (RPM)	2652.58	2387.33	3713.62	2652.58
F (mm/min)	169.765	105.042	118.836	95.493

3.2 Cutting tool

For the experiments in this study, only 2 type of tools, T1 and T2 are used. Whereas their performances in milling experiment will be compared and discussed. The specifications of the tools are stated in Table 2. T1 designed in fake outside diameter (OD) with different pitch (DP), while T2 designed in eccentric outside diameter (OD) with different pitch and different height (DPDH).

Table 2: cutting tools

	T1	T2
Type	Square endmill	Bullnose
Flutes	4	4
Design	Fake OD, DP	Eccentric OD, DPDH
Diameter	6	6
Special edge preparation	-	Yes
chamfer	-	1x45º
Helix angle	38º	40º
Coating	Uncoated	Uncoated

3.3 Cutting fluid

The cutting experiments will be conducted under three different cutting condition, where are: i) dry cutting, ii) flood cutting, and iii) MQL cutting. For flood cutting, the coolant used was PRETECH COOL SYN 2188, where the coolant nozzles were installed on the spindle. In MQL cutting, an extra nozzle was required to installed as shown in Figure 4, the fluid used was UNICUT JINEN MQL, sprayed with air pressure of 0.8MPa, the distance of 8mm and angle of 30º [27] was set between nozzle and tool tip.

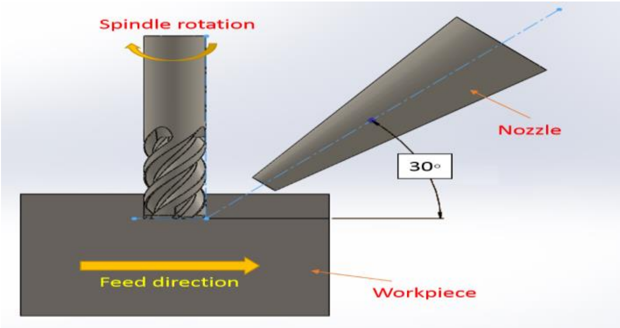

Figure 4: MQL setup

4. Result and Discussion

4.1 Cutting force

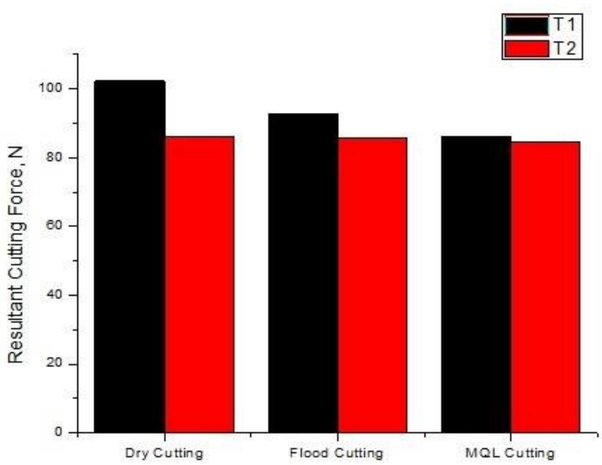

Figure 5: Cutting force for standard side milling with various cutting conditions

The resultant cutting force for side milling (standard) shown in Figure 5. For cutting tool T1, the cutting force are 102.33N, 92.80N, and 85.94N in dry cutting, flood cutting, and MQL cutting respectively. The reductions of cutting force are 9.31% in flood cutting and 16.02% in MQL cutting. While for T2, the cutting force are 86.08N, 85.65N, and 84.43N in dry cutting, flood cutting, and MQL cutting respectively.

In all of the cutting conditions, that is, dry cutting, flood cutting, and MQL cutting, T2 show the lower cutting force values compared to T1. The most reduction of cutting force between T1 and T2 was found at dry cutting, that is 15.88% or 16.25N. In flood cutting, the cutting force of T2 is 7.70% lower to T1, while in MQL cutting, the cutting force of T2 is 1.73% (1.49N) lower than T1. Since the cutting force is strongly influenced by tool wear, we can simply assume that the significant drop of cutting force for cutting tool T2 in dry cutting can be caused by low tool wear rate.

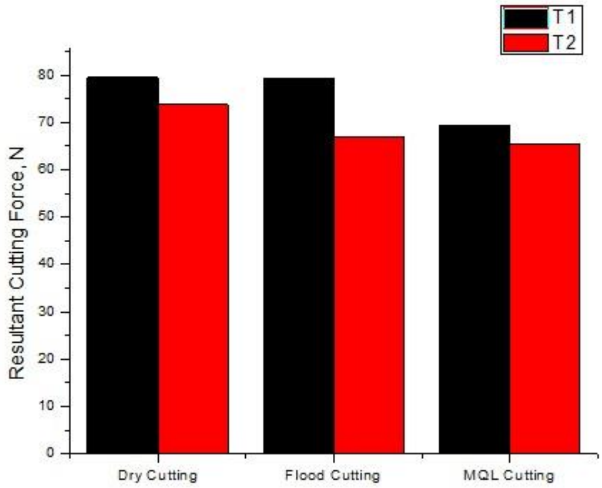

Figure 6: Cutting force for side roughing with various cutting condition

Figure 6 show the force measured in side roughing. For cutting tools without edge preparation T1, the cutting forces are 79.66N, 79.27N, and 69.45N in dry condition, flood condition, and MQL condition respectively. For cutting edge-prepared endmill T2, the cutting forces are 73.74N, 66.88N, and 65.36N for dry cutting, flood cutting, and MQL cutting respectively. For every conditions, T2 generated lower a cutting force than T1, the reductions of cutting force are 7.43% in dry condition, 15.63% in flood condition, and 5.89% in MQL condition. Compare to dry condition, the cutting force for T1 decreased only 0.49% in flood condition and 12.82% in MQL condition, while the cutting force for T2 decreased 9.30% in flood condition and 11.36% in MQL condition. Higher improvement on cutting force assisted by MQL condition than flood condition was observed for both T1 and T2 [12].

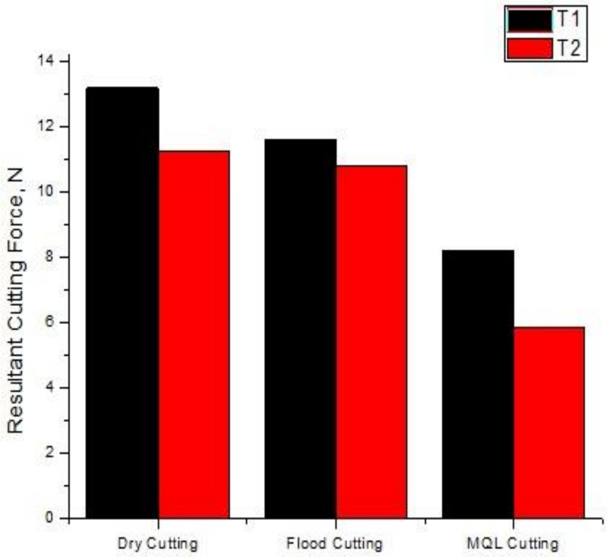

Figure 7: Cutting force for side finishing with various cutting condition

The cutting force for side finishing process as shown in Figure 7 is much lower than that in standard side milling and side roughing due to low radial depth of cut with only 0.2mm. For endmill with cutting edge preparation T1, the cutting forces are 13.18N, 11.61N, and 8.19N in dry, flood, and MQL conditions respectively. For endmill with cutting edge preparation T2, the cutting forces are 11.26N, 10.78N, and 5.84N respectively. The reductions of cutting force are significantly since small changes in force can caused a large ratio difference in finishing experiments. Same as standard side milling and side roughing experiments, T2 performs better than T1 in terms of cutting force. Reduction of cutting force by T2 compared to T1 was 14.57% in dry condition, 7.15% in flood condition, and 28.69% in MQL condition. In MQL cutting, T2 has excellent performance with only mean cutting force of 5.84N, which is 48.13% lower than that in dry cutting. However, the reductions of cutting force are still small, lower than 3N, in every tests due to low feed and high cutting speed [15].

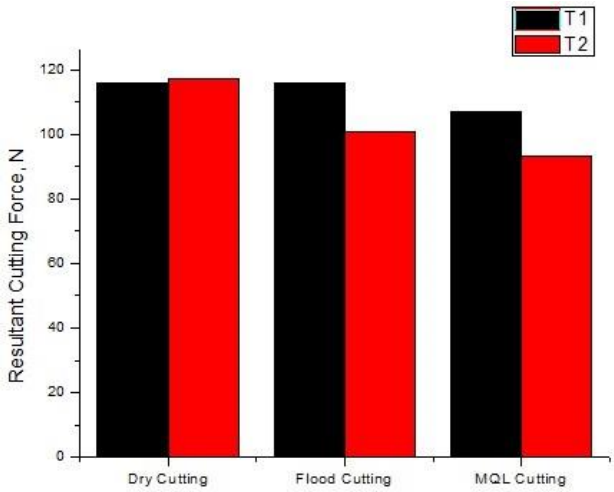

Figure 8: Cutting force for slot milling with various cutting conditions

Slot milling displayed the highest cutting force among all of the cutting operation due to highest radial depth of cut. For non-cutting edge prepared T1, the cutting forces were 115.84N in dry condition, 116.88N in flood condition, and 106.83N in MQL condition. While for cutting edge prepared T2, the cutting force were 117.11N in dry condition, 100.71N in flood condition, and 93.23N in MQL condition. Compare to other machining operation, a different phenomenon found in slot milling is that T2 is not always performs better than T1 in terms of cutting force. We can assume that the flood cutting did not helps in reduce the tool wear rate for non-cutting edge prepared tool T1 in slot milling due to slightly increase of cutting force was observed compared to dry condition. However, for edge prepared T2, the cutting force is measured slightly higher than that of T1 in dry condition.

Since the radial contact surface between tool and workpiece in slot milling is much higher than side milling, higher helix angle of the tool contribute higher cutting force in dry milling[16]. Another hypothesis can be made in this case is that during slot milling under dry condition, there is no cutting fluid to flush the formed chips that left at machined slot geometry. Since more chips with smaller size generated by chamfer geometry of edge prepared tool [28], the small chips that gather at the cutting area (machined slot) can caused rise in cutting force during machining process. However, further study on chips formation and tool wear in this experiment should be conducted to approve this hypothesis.

4.2 Surface roughness

Both of the bottom and side machined surfaces were measured to obtain their surface roughness in this study. Since the radial depth of cut for finishing cut is too small (0.2mm), the stylus of surface roughness tester cannot measure the roughness of machined bottom surface. Hence, there is no data of the bottom surface roughness for this particular cutting.

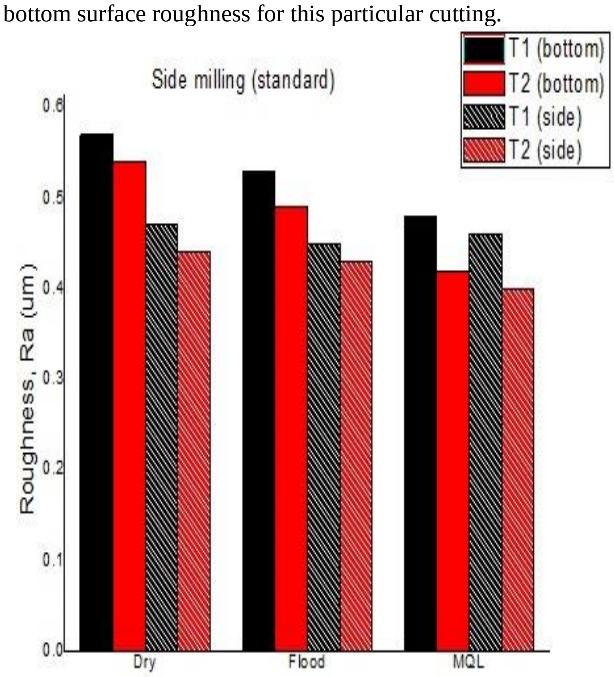

Figure 9: Surface roughness for side milling (standard) with various cutting condition

The surface roughness by T2 presented lower value than T1 in every cutting condition. For T1, reductions in roughness of 7.02% in flood condition and 19.30% in MQL condition were observed. For T2, the reductions of roughness were observed 9.26 in flood condition and 25.93% in MQL condition. The T2 can be said improve the cutting performance in term of surface roughness in each cutting condition, and MQL brings more benefits to the cutting compared to flood cutting.

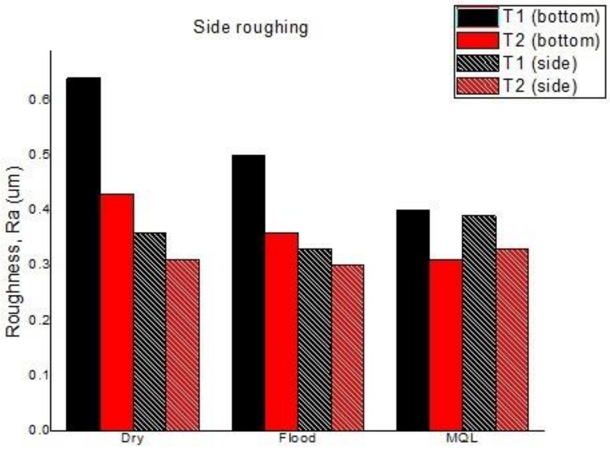

Figure 10: Surface roughness for side roughing with various cutting conditions

The surface roughness in side roughing was shown in Figure 10, endmill with cutting edge preparation T2, performed much better than that without edge preparation T1 in term of machined surface roughness for every cutting conditions. Cutting fluid utilization have observed reduced the roughness of machined surface for both T1 and T2, whereas lower roughness presented under MQL condition than that under flood condition. For T1, surface with roughness of 21.88% lower was produce under flood cutting, surface with roughness of 37.5% lower was produced under MQL cutting. For T2, roughness of machined surface reduced 16.28% under flood cutting, and 27.91% under MQL cutting.

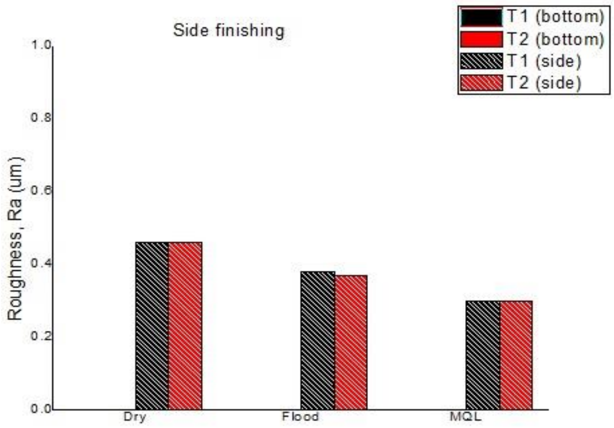

Figure 11: Surface roughness for side finishing with various cutting conditions

As in Figure 11 showed, difference with other side milling processes, roughness of machined surface shows almost the same values for both cutting tool with and without edge preparation under dry condition as well as MQL condition. Only 2.63% or 0.1µm of roughness reduction observed in flood condition by T2 compared to T1. The result is abnormal when simply verified with the cutting force result because T2 show excellent performance in reducing cutting force. However, the largest difference of cutting force observed in side finishing is still small (lower than 3N) even though the ratio of change is high. Small change in cutting force, which is lower than 3N, did not significantly brings benefits toward surface roughness.

Figure 12 shows the surface roughness obtained in slot milling. In dry cutting, both T1 and T2 produced the machined surface with same roughness of 0.67µm. Inference can be made is both T1 and T2 experience large cutting load at their edges so that even the prepared cutting edge on T2 did not contribute much in wear resist. This statement can be strengthened by result of cutting force that state the cutting force of T1 and T2 has almost same values for slot milling under dry condition. Clear reduction in machined surface roughness were found in flood cutting as well as MQL cutting, whereas, the cutting edge prepared tool T2 observed performs better than non-cutting edge prepared tool T1. Decrease of 14.29% of surface roughness was presented by T2 than T1 under flood condition and a drop of 17.65% of roughness was presented under MQL condition.

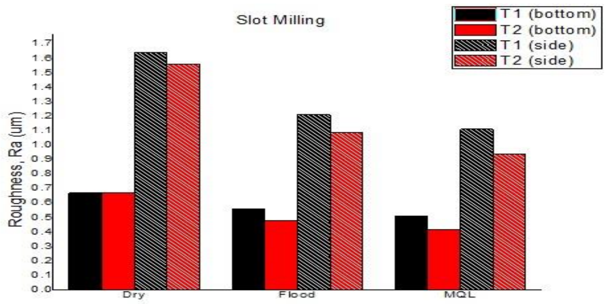

Figure 12: Surface roughness for slot milling with various cutting condition

In this study, cutting tool with edge preparation, T2, generally performed better than cutting tool without edge preparation, T1, in terms of cutting force and surface roughness of machined surfaces.

Since T2 are prepared by drag finishing method in this study, T2 have smoother rake surface than T1 and the deformations on cutting edge are removed [8]. According to the formation of chip, the chips flow with the direction parallel to the angle of rake face on cutting edge[28, 29]. Therefore, rougher rake face of T1 produced higher cutting force compare to T2 with smoother rake face due to friction occurred between formed chips and rake face of cutting tool.

Besides, theoretically higher heat will be generated by T1 because of higher friction than T2 during cutting process, but this statement should be verified by cutting heat experiment.

5. Conclusion

In conclusion, the objectives of the study are achieved. The machining performance of stainless steel 316L is investigated by experiments. The cutting tool (endmill with diameter of 6mm used in this study) with cutting edge preparation are trend to produce lower cutting force as well as machined surface roughness in machining process on stainless steel 316L. Sharp cutting edge are believed has lower strength that leads to lower wear resistant. The sharp edge can be removed by cutting edge preparation by increase the cutting radius to strengthen the edge geometry. An improvement of machining performance observed with utilization of cutting fluid every machining processes. Minimal Quantity Lubricant (MQL) method that spray the natural-oil based lubricant in "mist" phase provides a better machining condition for stainless steel 316L. By using air pressure of 0.4Mpa, 30º of nozzle angle to tool tip, and 8mm distance between nozzle and tool tip, MQL produced lower cutting force and surface roughness than flood cutting.

Acknowledgement

This work is supported by the Office for Research, Innovation, Commercialization and Consultancy Management (ORICC) on TIER 1 grant of Universiti Tun Hussein Onn Malaysia (UTHM). This work also supported by HPMT industries Sdn. Bhd. Shah Alam by supplying the cutting tool used in this research project.

References

[1] M. A. Amran *et al.*, "Effects of machine parameters on surface roughness using response surface method in drilling process," *Procedia Eng.*, vol. 68, pp. 24–29, 2013.

[2] J. Fernández-Pérez, J. L. Cantero, J. Díaz-Álvarez, and M. H. Miguélez, "Influence of cutting parameters on tool wear and hole quality in composite aerospace components drilling," *Compos. Struct.*, vol. 178, pp. 157–161, 2017.

[3] A. Z. Sultan, S. Sharif, and D. Kurniawan, "Effect of Machining Parameters on Tool Wear and Hole Quality of AISI 316L Stainless Steel in Conventional Drilling," *Procedia Manuf.*, vol. 2, no. February, pp. 202–207, 2015.

[4] M.R Ibrahim, E.A Rahim, M.I Ghazali, Z. O Goh. "Experimental analysis on ultrasonic assisted turning (UAT) based on innovated tool holder in the scope of dry & wet machining," *5th Inter. Conference on mechanical and manufacturing engineering ICME14 Applied Mechanics and Materials.*, vol. 660, pp.104–108, 2014.

[5] E. Uhlmann, D. Oberschmidt, Y. Kuche, A. Löwenstein, and I. Winker, "Effects of Different Cutting Edge Preparation Methods on Micro Milling Performance," *Procedia CIRP*, vol. 46, pp. 352–355, 2016.

[6] Z. Mohid, N.M Warap, S. Hassan, M.I.S. Ismail, R. Ibrahim, E. A Rahim, "Numerical analysis of laser heating for laser assisted micro milling application", *4th Inter. Conferecence on mechanical and manufacturing engineering, ICME13*, Applied Mechanics and Material *Procedia CIRP*, vol. 465-466, pp. 720–724, 2013.

[7] H. Rachmat, T. Mulyana, S. B. H. Hassan, M. R. Ibrahim "Design selection of in-UVAT using MATLAB fuzzy logic toolbox," *The 2nd International conference on soft computing and data mining, SCDM-201.*, vol. 549, no. 3, pp.538–545, 2017.

[8] E. A Rahim, A. A Rahim, M. R. Ibrahim, Z. Mohid, "Experimental investigation of supercritical carbon dioxide ($SCCOO_2$) performance as a sustaianable cooling techique," 13th Global Conference on Sustaiable Manufacturing, GCSM 2015, *Procedia CIRP.*, vol. 40, pp. 638–642, 2015.

[9] P. C. Priarone, S. Rizzuti, L. Settineri, and G. Vergnano, "Effects of cutting angle, edge preparation, and nano-structured coating on milling performance of a gamma titanium aluminide," *J. Mater. Process. Technol.*, vol. 212, no. 12, pp. 2619–2628, 2012.

[10] P. Sivaiah and D. Chakradhar, "Effect of cryogenic coolant on turning performance characteristics during machining of 17-4 PH stainless steel: A comparison with MQL, wet, dry machining," *CIRP J. Manuf. Sci. Technol.*, vol. 21, pp. 86–96, 2018.

[11] L. T. Tunc, Y. Gu, and M. G. Burke, "Effects of Minimal Quantity Lubrication (MQL) on Surface Integrity in Robotic Milling of Austenitic Stainless Steel," *Procedia CIRP*, vol. 45, pp. 215–218, 2016.

[12] S. Ekinovic, H. Prcanovic, and E. Begovic, "Investigation of Influence of MQL Machining Parameters on Cutting Forces during MQL Turning of Carbon Steel St52-3," *Procedia Eng.*, vol. 132, pp. 608–614, 2015.

[13] S. B. Kedare, D. R. Borse, and P. T. Shahane, "Effect of Minimum Quantity Lubrication (MQL) on Surface Roughness of Mild Steel of 15HRC on Universal Milling Machine," *Procedia Mater. Sci.*, vol. 6, no. Icmpc, pp. 150–153, 2014.

[14] K. K. Joshi, R. Kumar, and Anurag, "An Experimental Investigations in Turning of Incoloy 800 in Dry, MQL and Flood Cooling Conditions," *Procedia Manuf.*, vol. 20, pp. 350–357, 2018.

[15] N. Rajesh Mathivanan, B. S. Mahesh, and H. Anup Shetty, "An experimental investigation on the process parameters influencing machining forces during milling of carbon and glass fiber laminates," *Meas. J. Int. Meas. Confed.*, vol. 91, pp. 39–45, 2016.

[16] [16]P. Kolar, P. Fojtu, and T. Schmitz, "On Cutting Force Coefficient Model with Respect to Tool Geometry and Tool Wear," *Procedia Manuf.*, vol. 1, pp. 708–720, 2015.

[17] B. Denkena, J. Koehler, and M. Rehe, "Influence of the honed cutting edge on tool wear and surface integrity in slot milling of 42CrMo4 steel," *Procedia CIRP*, vol. 1, no. 1, pp. 190–195, 2012.

[18] K. D. Bouzakis *et al.*, "Effect of cutting edge preparation of coated tools on their performance in milling various materials," *CIRP J. Manuf. Sci. Technol.*, vol. 7, no. 3, pp. 264–273, 2014.

[19] F. M. Bordin and R. P. Zeilmann, "Effect of the cutting edge preparation on the surface integrity after dry drilling," *Procedia CIRP*, vol. 13, pp. 103–107, 2014.

[20] M. K. N. Khairusshima and I. S. S. Sharifah, "Study on Tool Wear during Milling CFRP under Dry and Chilled Air Machining," *Procedia Eng.*, vol. 184, pp. 506–517, 2017.

[21] P. J. Liew, A. Shaaroni, N. A. C. Sidik, and J. Yan, "An overview of current status of cutting fluids and cooling techniques of turning hard steel," *Int. J. Heat Mass Transf.*, vol. 114, pp. 380–394, 2017.

[22] H. Rachmat, T. Mulyana, S. B. H. Hasan, and M. R. Bin Ibrahim, "Design selection of In-UVAT using MATLAB fuzzy logic toolbox," *Adv. Intell.*

Syst. Comput., vol. 549 AISC, pp. 538–545, 2017.

[23] H. Lian, Z. Guo, Z. Huang, Y. Tang, and J. Song, "Experimental research of Al6061 on ultrasonic vibration assisted micro-milling," *Procedia CIRP*, vol. 6, pp. 561–564, 2013.

[24] I. I. Rasidi, N. H. Rafai, E. A. Rahim, S. A. Kamaruddin, H. Ding, and K. Cheng, "An investigation of cutting mechanics in 2 dimensional Ultrasonic Vibration assisted milling toward chip thickness and chip formation," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 100, no. 1, 2015.

[25] H. Ding, S. J. Chen, R. Ibrahim, and K. Cheng, "Investigation of the size effect on burr formation in two-dimensional vibration-assisted micro end milling," *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*, vol. 225, no. 11, pp. 2032–2039, 2011.

[26] M. Hadad and A. Sharbati, "Thermal Aspects of Environmentally Friendly-MQL Grinding Process," *Procedia CIRP*, vol. 40, pp. 509–515, 2016.

[27] A. Attanasio, M. Gelfi, C. Giardini, and C. Remino, "Minimal quantity lubrication in turning: Effect on tool wear," *Wear*, vol. 260, no. 3, pp. 333–338, 2006.

[28] N. Fang and Q. Wu, "The effects of chamfered and honed tool edge geometry in machining of three aluminum alloys," *Int. J. Mach. Tools Manuf.*, vol. 45, no. 10, pp. 1178–1187, 2005.

[29] I, Rasidi, E.A. Rahim, A.A. Ibrahim, N. A. Maskam, S. C. Ghani, " The effect on the application of coolant and ultrasonic assisted micro milling on machining performance*"5th Inter. Conference on Mechanical and Manufacturing Engineering 2014, ICME2014, Applied Mechanics and Materials*, vol. 660, pp. 65-69, 2014