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ORIGINAL ARTICLE

Utilization of Minimum Quantity Lubrication (MQL) Chip Fan on SS304 During Milling Process to Increase Carbide Tool Life

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ABSTRACT – Minimum quantity lubrication (MQL) is the most used recent method in the milling process that is economical and environmentally friendly. The MQL method can reduce the temperature during the milling process. The high temperature that occurs in the carbide tool will affect the tool's life. The use of cooling fluid is a common method to reduce high temperatures. However, the remaining cooling fluid has an impact on the pollution of the environment. Therefore, in this study, a novel approach for a cooling system based on the combined MQL method and fan cooling device was introduced and called an MQL Chip fan. The effect of the MQL Chip fan on the temperature, tool life, and surface roughness was investigated. The Taylor equation was used to calculate tool life based on temperature data from an experimental investigation. Subsequently, the quality inspection was conducted by using a surface roughness tester. The spindle speed and depth of cut have proven to make a great impact on the peak temperature, but, there is an optimal point where spindle speed made a turbulence and the tool had a passive cooling system. The utilization of the MQL Chip fan has decreased temperature by more than half at a medium speed of 2241 rpm and made a high contribution for low-speed processing and only a slight contribution for high-speed processing. Based on Tool Life prediction, 3600 RPM with a 3 mm depth of cut has more efficient performance compared to 2241 rpm with the same depth of cut. The utilization of the MQL Chip fan contributes significantly to the roughness value; the Ra value decreased from 1.374 μm to 0.461 μm. It has been proven that the utilization of an MQL Chip fan in the milling process reduces temperature and also increases the tool life.

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INTRODUCTION

The recent development of the manufacturing process requires high awareness of environmental and health problems [1], [2]. It is required that a process should be clean, less polluting, minimize the use of natural resources, reducing social and health impacts [3, 4]. The milling process is a major part of the machining process that uses high-intensity energy and material waste. Therefore, it needs to be environmentally friendly [5]. In the milling process, several parameters influence the quality and efficiency of production. The parameters are cutting depth, cutting speed, cutting force, tool geometry, tool treatment, tool coating, tool types, and workpiece material. There is friction between the workpiece area and the tool during the workpiece-cutting process, causing such high heat generation and resulting in an increase in temperature between the workpiece and the tool. Increasing temperature in the tool and the workpiece is a troublesome matter because it decreases tool life and impacts the quality of the workpiece surface [6]-[8].

Taylor et al. [9] studied Minimum Quantity Lubricant (MQL) in milling. Traditionally, cooling fluid is applied in the milling process to increase tool life and improve surface quality. Kovac et al. [10] investigated the use of cooling fluid is costly and estimated to be around 17% of the operational cost. Baohai et al. [11] have approached the use analytics model by reducing heat generated in the critical areas of the tool and workpiece. Le Coz et al. [8] take measurements to reduce the temperature of the tool use optimation the condition of the tool. Singh et al. [12] explored the potential of the MQL and stated the cooling process of using cooling liquid to reduce the temperature in high-speed milling had been proven ineffective. Deshpande et al. [13] reviewed that conventional cooling is generally made of water, oil, or gas and the remnants of these liquids could pollute the environment. There are many disadvantages of using conventional cooling, such as the requirement of extra floor space, pumping system, storage space, filter, recycling, and coolant.

Deshpande et al. [13] proposed an innovative approach by using nanofluid for the cooling method; the nanofluid minimizes surface friction and cutting forces, hence reducing the tool abrasion and implementing a dry milling process. However, this method has a drawback, an increased temperature and only applied to the high-speed cutting process. In their opinion, the MQL method could produce excessive heat when applied to hard material, resulting in reducing tool hardness and decreasing tool wear. Ravi et al. [14] investigated the cooling process by using cryogenic liquid. The result was successful, it was increasing the efficiency of machine components through lubrication pressure, following a better impact on the workpiece surface. Singh et al. [15] investigate the performance of alumina-graphene hybrid nano-cutting fluid in hard turning. The turning operation was applied to SS304 under the MQL technique. The result shows that the

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hybrid nanofluid can reduce significantly surface roughness, thrush force, and feed force. In other research by Sharma et al. [16], the application of a hybrid nanofluid using alumina-graphene in AISI304 steel could reduce the tool flank wear and nodal temperature.

Pereira et al. [17] studied the cryogenic-MQL combined method that can reduce technical and environmental problems. Another method to improve the quality of the milling process is by coating the carbide tool, which has an impact on surface roughness [18]. Karandikar et al. [19] have approached tool life prediction by classifying logistics and datasets and ways to reduce the impact on the environment in the milling process, referring to the ISO 14040 (2006) and ISO 14044 standards. Currently, the milling process can map all the possibilities that occur to reduce energy consumption, especially during the processing stage [20]. Karandikar et al. [21] studied the Taylor equation and its derivatives for tool life prediction in the milling process to reduce material consumption.

Varghese et al. [22] investigated an eco-friendly system that can integrate environmentally friendly technology, automatic control technology, and information technology or can enable real-time monitoring. Lee et al. [23] studied the increasing enforcement of environmental regulations in many countries. Many people are becoming interested in technologies for recycling cutting fluids and metal scraps. The MQL method uses oxygen, whereas the stainless steel (SS) 304 material results in less tool wear, cutting forces, and better surface quality [24]. Another capability of the MQL method is that it is environmentally friendly, which is a viable alternative to wet lubrication technology [25]. Milling processes that require cooling, either using the dry milling process without using cooling or using cooling either in the form of coolant fluid, nanofluid, cryogenic, or MQL, are still less effective and efficient in their application. Cooling in the milling process affects tool life and workpiece surface roughness.

Therefore, it is necessary to improve the quality of the milling process, which has an impact on the tool life and the quality of the workpiece surface [22]. In this work, We aim to investigate the impact of using an MQL Chip fan on tool life and surface roughness. The effect of the dry milling process using the MQL Chip fan and without the MQL Chip fan will then be compared. Ultimately, we will measure the quality of the workpiece surface and tool life, especially in the finishing and roughing processes.

MATERIALS AND METHODS

Materials

The tool used in this experiment was a tungsten carbide with an end-mill of 12 mm in diameter and with an angle of 30° as shown in Figure 1, and the mechanical properties are listed in Table 1. Stainless steel 304 (SS304) was used as sample workpiece material with the chemical composition listed in Table 2 and mechanical properties in Table 3. A conventional milling machine was used with machine specifications, as listed in Table 4.

Table 1. Mechanical properties of carbide tool [26]

Parameters	Tool (tungsten carbide)
Density, *ρ*	11900 kg/m^3
Thermal Conductivity, *k*	50 W/m/ °C
Poisson's ratio, *υ*	0.22
Young's modulus, *E*	534 Gpa
Specific heat, *Cp*	400 J/kg/ °C

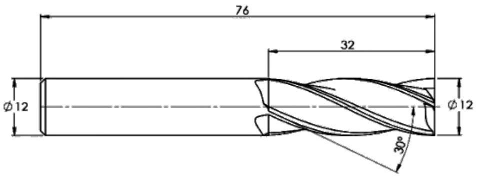


Figure 1. Dimensions of tungsten carbide end-mill

Table 2. Chemical composition of SS 304 [12]

Element	N	C	P	Mn	Si	Cr	S	Ni
wt.%	0.1	8	0.045	2	0.75	18	0.03	8.12

Table 3. Mechanical properties of workpiece SS 304 [27]

Parameter	Workpiece SS 304
Density	8.00 g/cm3
Melting point	1450 °C
Modulus of elasticity	193 Gpa
Electrical resistivity	0.72 × 10-6 Ω.m
Thermal conductivity	16.2 W/m.K
Thermal expansion	17.2 × 10-6/K

Table 4. Specification of conventional milling machine

Power	5 Hp spindle motor
Table	229×1067 mm
Spindle taper	NST# 30, or R8
Special square head for step speed	

Methods

The experimental machine setup is shown in Figure 2. The experiment used a conventional vertical milling machine, the sample workpiece was in the form of a square SS304 material, and the carbide tool was installed. The MQL Chip fan process was carried out with the fan facing the tool and the workpiece so that it was centered on the milling process area. MQL Chip fan specification is listed in Table 5. Temperature measurement in the milling process was carried out by the non-contact method [7]. The data was carried out by measuring the temperature on the tip of the tool using a thermal imaging camera. The video from the thermal imaging camera was recorded during the process. And then, it was evaluated by observing frame by frame to capture the highest temperature during the process from start to finish. The specifications of the thermal imaging camera is shown in Figure 3, and the specification is listed in Table 6. The temperature data were collected continuously during the milling process by cutting the SS304 material. The measured temperature was aimed at a critical area between the tool and the workpiece during the cutting process. The temperature data was then used to predict the tungsten carbide tool life [5].

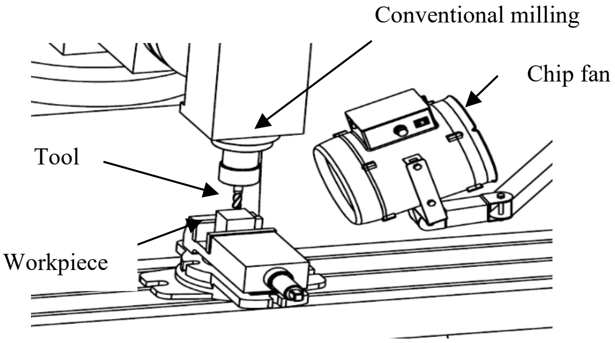


Figure 2. Experiments in the milling process

Table 5. Specification of chip fan

Rated voltage	DC 12V - 24V
Rated current	0.32A
Speed	6000 rpm
Diameter fan	150 mm
Velocity	9.86 m/s
Pressure	628.525 Pa

A surface roughness test (Ra) was carried out to determine the quality of the milling process of the SS304 workpiece. There was a total of 36 data variations, with three parameters spindle speed, roughing, and finishing. The spindle speed variations were 958 rpm, 2241 rpm and 3600 rpm, the feed rate for each rpm consecutively was 38 mm/min, 90 mm/min, and 144 mm/min. The finishing process (cutting thickness of 0.3 mm, 0.6 mm, and 0.9 mm) and roughing process (thickness of 1 mm, 2 mm, and 3 mm) total parameters have six variations. Thus, there were a total of 18 variations for each dry milling with a chip fan and without a chip fan.

To determine the effect of chip fan application during the milling process, the results were compared to the results of dry milling without the MQL Chip fan [28]. Temperature measurement in the milling process is carried out by the non-contact method [7]. This research was conducted on the milling process by measuring the temperature on the tip of the tool using a thermal image camera. The specifications of the thermal image camera used can see in Figure 3, and the specification of the thermal image camera is in Table 6.

Figure 3. Thermal imaging camera

Table 6. Specification of thermal image camera

Product Specification	Value
Air humidity	20~80%RH (non-condensing)
Vibration	2G
Storage temperature	-40~ +60°C
Operating temperature	-15~ +50°C
Analysis function	Mean point measurement, hot/cold-spot recognition, Delta T
Measuring range	-30 to +100° C; 0 to +650° C

Governing Equation: Determining Tool Life

General Taylor equation was used to predict the tool life as in Eq. (1). The Taylor equation can be written as follows [10]:

$$\mathrm{v}.T^{n} = C \tag{1}$$

where v = cutting speed (m/min); *T* = tool life (minutes); *n* = exponential tool life; *C* = constant. In Taylor's Eq. (1), the tool life is generally only affected by cutting speed. The feeding and depth of cut factors have not been used as influential parameters to predict tool life. The General Taylor equation was derived by adding both factors shown in Eq. (2) [10]:

$$T = \frac{C}{v^{n}.f^{x}.a^{y}} \tag{2}$$

where *T* = tool life (minutes); v = cutting speed (m/min); *f* = feeding (mm/round); *a* = depth of cut (mm) *n, x, y* = exponential of tool life. The Taylor's equation that has been derived that involves temperature as the main factor affecting tool life, using the temperature as a variable, the equation becomes Eq. (3) and Eq. (4) [10]:

$$T = C_{v}.\left(\frac{C_{\theta}}{\theta_{m}}\right)^{\frac{Z}{P}} \tag{3}$$

$$\theta_{m} = C_{\theta}.v^{P} \tag{4}$$

where *T* = tool life (minutes); θ_m= temperature (ºC); C_v and C_θ = constant; *Z* and *P* = exponential constant [10]. Furthermore, the surface roughness of the milling workpiece was evaluated by using the surftest SJ-310 Series Portable Surface Roughness Tester [18]. The measuring instrument and the specifications as shown in Figure 4 and Table 7. However, consideration was needed because the equation had a limitation cutting range parameter. The author stated that the equation assumption was a single tooth cutter, while in this research performing multi-tooth cutters (three-tooth cutters). But, the author did say it is possible to use the equation for multi-tooth cutters. The range cutting speed for a single tooth in Kovac et al. [10] was 1.83-4.65 m/s. In this research, the cutting speed with a triple tooth was 0.60 m/s; 1.41 m/s; 2.26 m/s. If the triple tooth were converted to a single tooth, it would be 1.81 m/s, 4.22 m/s, and 6.79 m/s.

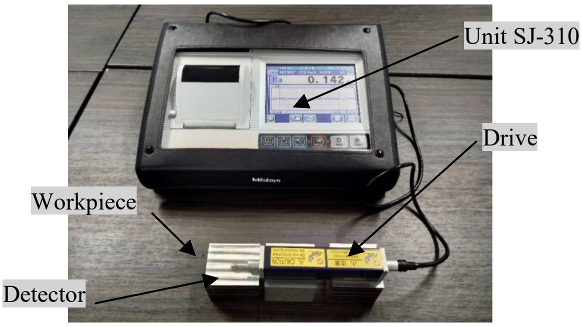


Figure 4. Portable surface roughness tester

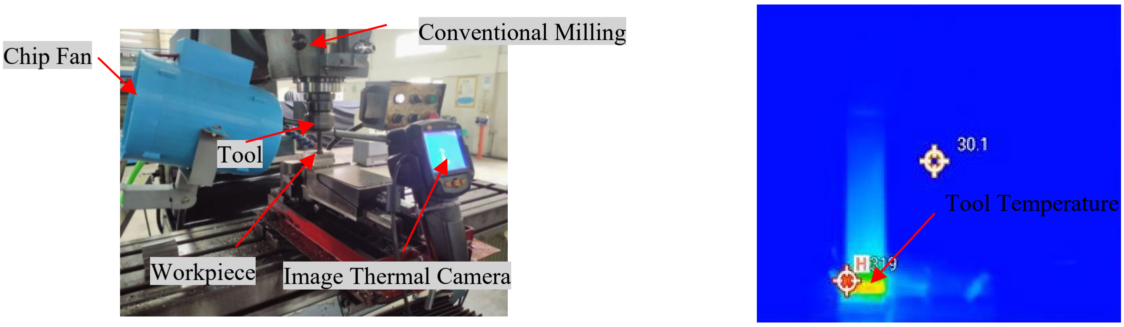
Table 7. Specification of portable surface roughness tester

Measuring	X-axis : 16.0 mm
Detector: range:	360 micron (-200 micron + 160 micron)
Range/resolution	360 micron/0.02 micron, 100 micron/0.006 microns, 25 micron/0.002 micron
Measuring speed	0.25 mm/s, 0.5 mm/s, 0.75 mm/s
Parameter	Ra, Rc, Ry, Rz, Rq, Rmax, Rp, Rv
Filter	Gausian, 2CR75, PC75

RESULTS AND DISCUSSION

Experimental Temperature Data

Figure 5 shows the experimental setup and temperature image display during the dry milling process using an MQL Chip fan. It presents the experimental process where temperature data is taken at the tip of the tool using a thermal camera image during the dry milling process and the MQL Chip fan. The temperature data was collected when the steady-state condition occurred. It happened several seconds after the tool had the first touch. In the steady-state condition, the temperature average was then used as the temperature data. The steady-state temperature result data from the dry milling process without using an MQL Chip fan were obtained both for the finishing and roughing process, as shown in Table 8.



(a) (b)

Figure 5. The experiment of milling process (a) setup experiment, (b) result on display image thermal camera

Table 8 shows the temperature data from the dry milling finishing process. There was a significant increase in the temperature when the spindle speed was increased from 958 rpm to 2241 rpm. It happened in all three depths of cut variation. The incremental were very high around 66 to 137°C. However, when the rotation was increased from 2241 rpm to 3600 rpm, the temperature was slightly increased for the depth of cut 0.6 mm and 0.9 mm. The increment is around 9 to 23°C. In contrast, the temperature depth of the cut 0.3 mm was decreased from 185°C to 147°C. Therefore, the dry-milling finishing (without Chip-Fan) at high-speed rotation (2241 rpm dan 3600 rpm) had significant increasing in temperature compared to the low-speed rotation of 958 rpm.

Table 8. The temperature of the dry milling-finishing and dry milling roughing process

Spindle speed (rpm)	Dry milling-finishing			Dry milling roughing process		
	Deep of cut (mm)					
	0.3	0.6	0.9	1.0	2.0	3.0
958	119°C	102°C	101°C	105°C	159°C	163°C
2241	185°C	220°C	238°C	281°C	331°C	477°C
3600	147°C	243°C	247°C	264°C	303°C	366°C

From the dry milling roughing process, the comparison temperature data between the depth of cut 0.3 to 1 mm in 958 rpm were no significant temperature deviation (around 101-119°C). However, when the depth of cut was increased from 1 mm to 2 mm, it was increased significantly around 50°C. The temperature only slightly increased for the depth of cut of 2 mm to 3 mm. In roughing process, a similar result was acquired when the spindle speed increased from 958 rpm to 2241 rpm. The result showed that the temperature increased significantly more than doubled (almost tripled). It was proven that increased spindle speed to 2241 RPM resulted in an excessive heat generation that leads to decreased tool life significantly. Nevertheless, increased the speed to 3600 rpm had a different result compared to 2241 rpm. It was shown that 3600 rpm had lower temperature instead. This effect occurred because there was probably better-forced convection when the spindle speed increased from 2241 to 3600 rpm, which led to lowering the temperature [29].

Even more, increased in the depth of cut would increase temperature consistently at 2241 rpm. In general, the temperature data showed an evidence that the depth of cut made an impact contribution to increased the temperature. The temperature data from the dry milling process using with MQL Chip fan were obtained both for the finishing and roughing process as shown in Table 9.

Table 9. The temperature of the finishing process and roughing process with MQL chip fan.

Spindle speed (rpm)	Finishing process			Roughing process		
	Depth of cut (mm)					
	0.3	0.6	0.9	1.0	2.0	3.0
958	69.6°C	88.6°C	97.5°C	90.5°C	138°C	145°C
2241	104°C	147°C	125°C	149°C	152°C	206°C
3600	129°C	221°C	236°C	247°C	279°C	319°C

Each temperature at 958 rpm from finishing and roughing was decreased around 15 to 50°C. This was a good decrement result when low-speed rpm was used. A significant contribution from the MQL Chip fan was made in 2241 rpm. The temperature decrements are almost halves (around 73 to 113°C, or around ~40%) for the finishing process and more than half (around 47 – 57%) for roughing process. This evidence showed that forced convection from the MQL Chip fan made a huge impact on the cooling processes [30].

Looking into the data depth of cut, 0.6 mm to 1 mm, relatively had a small difference in temperature variation in each rpm. Only at 2241 rpm, the similar temperature data showed up to 2 mm with slight variation (ex: 147, 125, 149, 152°C). A large gap temperature difference occurred between the depth of cut of 0.3 to 0.6 mm or 2 to 3 mm. Therefore, the best option for finishing the surface in order to minimize the high-temperature process was using a depth of cut of 0.3 mm at every spindle speed.

The decreased temperature at 3600 rpm was not significant enough when using the MQL chip fan. There probably existed air turbulence in the friction area that led the tool to have passive air circulation. So, when the chip fan was introduced to the system, the air turbulence from tool rotation prevented the forced air from the chip fan. Therefore, there was only a slight contribution in introducing a chip fan when a high-speed spindle rotation was used.

Prediction of Tool Life

In order to predict tool life, Eq. (3) and Eq. (4) were used by entering the temperature data. Where T=tool life (minutes), θ_m=input temperature (°C), Cv=550, C=61,872, Z=0.2022, and P=0.25 [31]. After performing tool life calculation, depth of cut and spindle rotation was used as the base x-axis and y-axis for surface plotting. Surface plotting between the depth of cut vs tool life and spindle speed vs tool life are presented in Figure 6 and Figure 7.

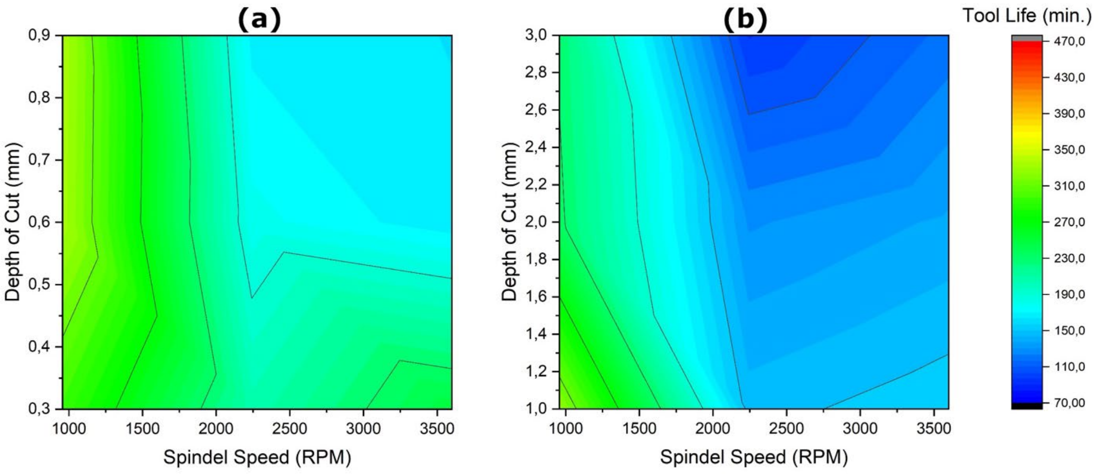


Figure 6. Prediction of tool life without using the MQL Chip fan for (a) finishing process and (b) roughing process

Figure 6 shows the tool life of the finishing and roughing process without an MQL Chip fan. The green region indicated in the surface plotting was between 230-350 minutes. The green to yellow region in the finishing process existed at 958 rpm, while in the roughing process only existed at 958 rpm with a 1 mm depth of cut. Figure 7 shows the tool life of the finishing and roughing process with the MQL chip fan. The orange to the red region indicated in the surface plotting was between 390-470 minutes. The red region in the finishing process existed at 958 rpm and 0.3 depth of cut; also this region's boundaries exist at lower than 2000 rpm and lower than 0.6 mm. While in the roughing process, a yellow region at 958 rpm with a 1 mm depth of cut exists. The properties of carbide tools are hard and highly wear-resistant at high temperatures [32]. In elsewhere literature [33], an evaluation to determine the tool life for the milling process can be done with only spindle speed variations. It is coherent with the result from Figure 6 and Figure 7, even though the depth of cut also contributed to determining tool life.

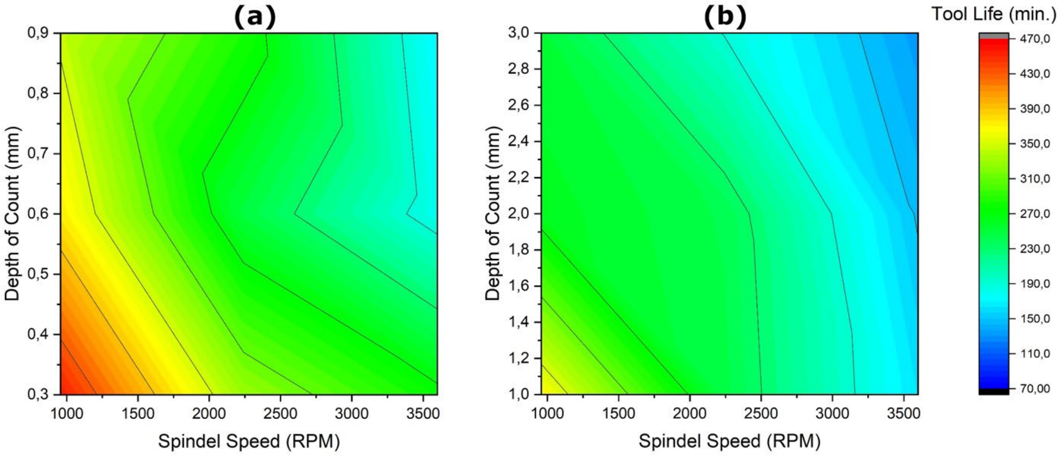


Figure 7. Prediction of tool life using the MQL chip fan for (a) finishing process and (b) roughing process

The length of time in the process machinery was influenced by the depth of cut and the cutting speed significantly, therefore, to optimize the effectiveness of tool life, efficiency must be calculated based on how much volume material could be processed, as shown in Eq.(5).

$$\mathrm{d}.\varnothing.v.T = Vol. \tag{5}$$

where: *d* = depth of cut, Ø = diameter tool, *v* = cutting speed (mm/min) and *T* = predicted tool life.

Table 10 presents volume calculation to predict how much volume material can be processed during dry milling using an MQL Chip fan. Two categories can be utilized for the MQL chip fan application. First, medium-speed processing (2241 rpm) with 90 mm/min cutting speed, and high-speed processing (3600 rpm) with 144 mm/min cutting speed. At both processing, the most efficient way to do a milling process was using a depth of cut 3 mm. As per the predicted volume, it could process at least 600 cm^3 or more. The highest potential from predicted volume was from high-speed processing, despite the predicted tool life is only 133 minutes, compared to medium-speed processing. Even though the MQL chip fan only slightly affected the cooling rate, it still manages the best efficiency of the milling process, and also high rpm could reduce the cutting force for the process [34].

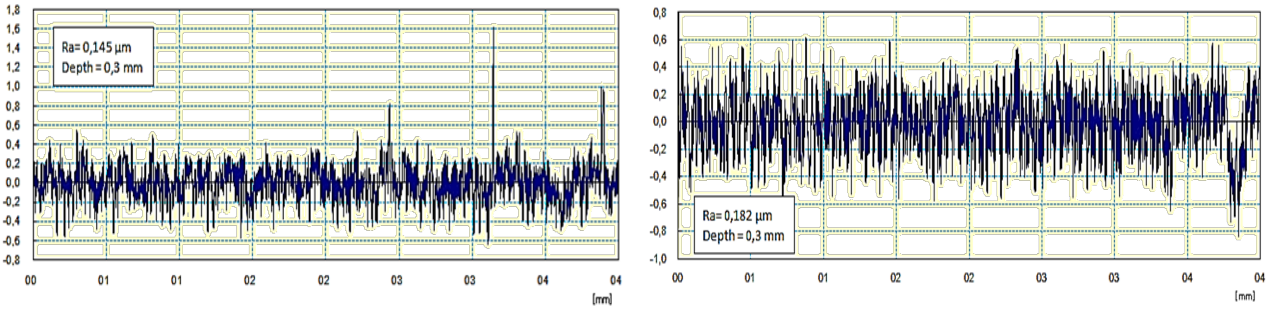
Table 10. Prediction tool life of the dry milling roughing process with MQL chip fan

DoC (mm)	958 rpm; v = 38 mm/min		2241 rpm; v = 90 mm/min		3600 rpm; v =144 mm/min	
	Predicted tool life (min.)	Predicted volume (cm^3)	Predicted tool life (min.)	Predicted volume (cm^3)	Predicted tool life (min.)	Predicted volume (cm^3)
1	368	168	246	266	163	282
2	261	238	242	523	148	511
3	251	343	189	612	133	689

However, high-speed milling process sometimes could impact surface roughness. Therefore, an evaluation of surface roughness was required as a consideration for reducing production costs [35]. In alternative to high-speed processing, medium-speed processing can be used for better roughness or used in harder material compared to SS304. The prediction of tool life is an important factor in modern manufacturing. Besides the economic impact, it is also important to minimize material waste [36]. It is important to change the rotation of the contact area so that the coefficient of friction and the cutting temperature decrease [37].

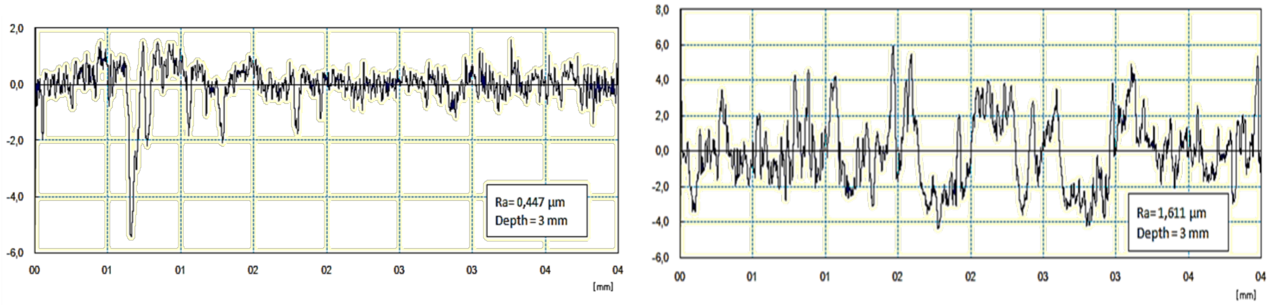
Surface Roughness Evaluation

High-speed processing at 3600 rpm has the best efficiency so far; however, using high rpm and high cutting speed leads to decreasing dimensional accuracy and surface quality. Therefore, surface roughness measurements were carried out only for 3600 rpm. The results of the surface roughness measurement for the finishing process are shown in Figure 8. Using an MQL chip fan had better surface roughness; the difference was 0.037 µm. The results of the surface roughness measurement for the roughing process are shown in Figure 9. Using the MQL chip fan had far better surface roughness; it increased the quality from *Ra*=1.611 µm to *Ra*=0.447 µm, with a difference of 1.164 µm.



(a) with MQL (b) without MQL

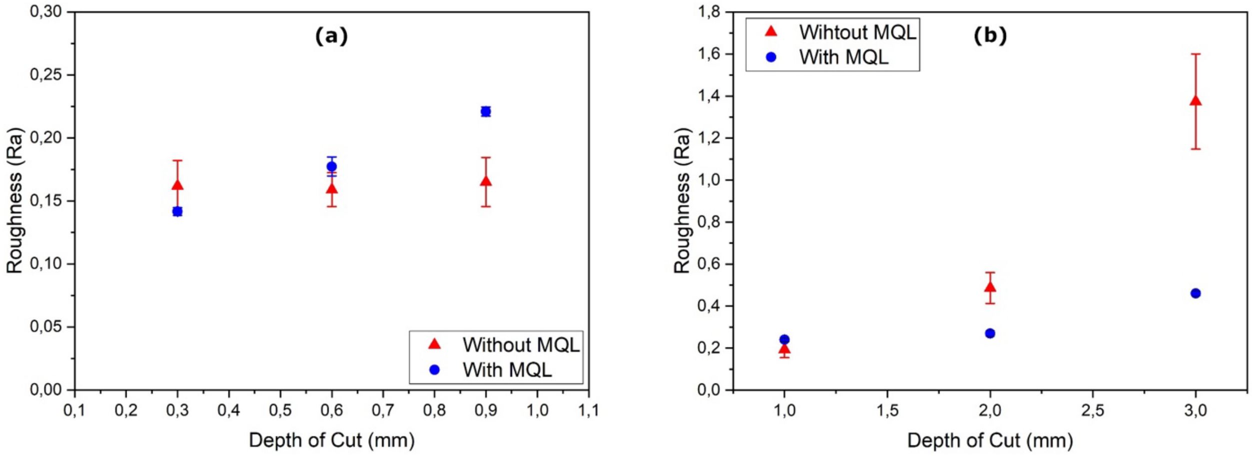
Figure 8. Roughness test on finishing process at 0.3 mm depth of cut



(a) MQL chip fan (b) dry milling

Figure 9. Result of roughness test on roughing process

Figure 10(a) shows the average roughness result of the finishing process; the average value was calculated from three repetition data in each depth. The result shown without the MQL chip fan had a stable average, whereas the data with MQL chip fan had shown increased steadily with a small deviation. The evaluation results show that the surface roughness value at a depth of 0.3 and 0.6 almost had the same result, both from using the MQL chip fan or without using it. But at a depth of cut of 0.9 mm, the surface roughness value in the MQL chip fan process had increased by more than 0.050 µm. Overall, the evaluation result of the workpiece surface roughness in the finishing process was equivalent to the results of the grinding process (Ra < 0.30) [37]. Figure 10(b) shows the surface roughness quality using the MQL chip fan at a depth of 1 mm almost had the same value, but for depth of cut of 2 mm and 3 mm were better than without using a chip fan. Especially for a depth of 3 mm, the difference was significant and improved the surface quality to almost near the finishing surface standard. Overall, the Ra value tends to be more stable during the finishing process. Figure 11 shows the machine surface image with Ra value for each image at (a) 0.179 µm, (b) 0.222 µm, (c) 0.462 µm and (d) 1.632 µm. The roughness data corresponded with the temperature data. The decrease in temperature comes from the decrease in friction between the tool and the workpiece. While the friction effect was the major cause of the quality of the roughness in a workpiece, therefore, the temperature in the tool can be correlated to the surface roughness result.



(a) (b)

Figure 10. Average roughness in (a) finishing process and (b) roughing process

Milling process parameters, both in finishing and roughing, are significantly influenced by the depth of cut and spindle speed, which then affects tool life and roughness [38, 39]. In the existing process, it can be stated that the MQL chip fan influences tool life and surface roughness quality. Surface roughness plays an important role in mechanical properties, especially in machining jobs that require high precision [40] and display product characteristics [41]. The process of using an MQL Fan chip compared to dry milling is more profitable and can reduce the operational coolant [42], resulting in a cleaner and healthier environment [43, 44].

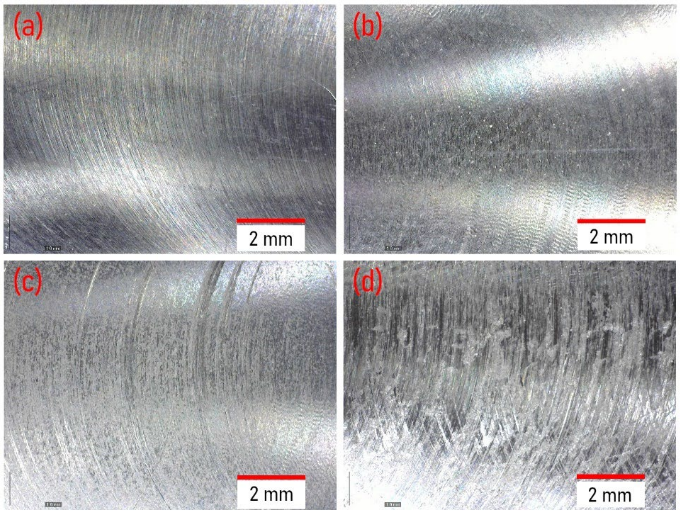


Figure 11. The physical appearance of (a) finishing with MQL chip fan - DoC 0.6 mm; (b) finishing with MQL chip fan - DoC 0.9 mm; (c) roughing with MQL chip fan - DoC 3 mm; (c) roughing dry-milling - DoC 3 mm

CONCLUSIONS

The effect of the MQL Chip fan on the steady-state temperature of the tool has been investigated. Two major parameters, the spindle speed (rpm) and depth of cut (mm), have proven to make a great impact on the temperature side. However, there is a turning point of spindle speed where turbulence occurred and the tool had a passive cooling system. In addition to external cooling equipment, the MQL chip fan greatly decreased temperature by more than half at medium speed of 2241 rpm. Also, the MQL chip fan made a high contribution for low-speed processing of 958 rpm and only a slight contribution for high-speed processing of 3600 rpm.

As per tool life prediction based on calculation, 3600 rpm with the depth of cut of 3 mm had the most efficiency, and 2241 rpm with the depth of cut came second. Then, the roughness value for the finishing process with parameter 3600 rpm almost had the same value for both using the MQL chip fan and not using it. However, the MQL chip fan reduces deviation significantly. For application purposes, a 0.3 mm depth of cut is better than the other two. For roughing process, utilization of the MQL chip fan did contribute significantly, from an average of 1.374 µm without using the fan to an average of 0.461 µm using the fan, decreasing around ~66%. Adding an MQL chip fan to the milling process has proven to reduce the workpiece and tool temperature and increase the tool life.

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