Effect of End Mill Geometry and Coolant Strategies on Machining Performance of Nickel Based Alloy Inconel 718

Kamaruddin Kamdani, Ng How Jieh, Erween Abd Rahim, Zazuli Mohid, Noor Hakim Rafai, Chew Kong Wong, and Afiff Latif

Abstract Inconel 718 requires proper cooling and lubrication due to its low thermal conductivity and high specific heat capacity at cutting area. In addition, proper selection of cutting tool geometry also contributes an impact to its performance. Therefore, the objective of this study is to compare the performance of minimum quantity lubricant (MQL) with flood cooling and also compare two types of end mill geometry when end milling of Inconel 718 in terms of cutting force and tool life. From the results, MQL condition shows the effectiveness of lubrication to cut Inconel 718 compared to flood coolant. The results of tool wear and cutting force shows significant improvement of MQL compared to flood coolant. In conclusion, MQL proved to provide enough lubrication on cutting zone while T2 was the best tools due to its geometrical features.

Keywords Inconel 718 · End milling · Tool geometries · Minimum quantity lubricant

1 Introduction

Machining process is basically highly demand in aerospace industry, particularly for nickel based super alloy [1–6]. It is due to its high hardness, good surface stabilization and excellence corrosion and oxidation resistance at extreme temperature. Inconel 718 is normally used to produce a component in turbojet engine because of its excellent characteristics [7]. It includes a hardening of the niobium era that provides elevated power and resistance to corrosion [8]. According to [9–13], high speed of machining Inconel 718 is not sufficient due to their poor machinability, associated with low thermal conductivity, thus producing high machining temperature.

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Emulsion type metalworking fluids and flood coolant systems have been most widely used for various metalworking industries. However, environmental concerns have increased cost to treat this type of coolant system fluid. Thus when it is disposed, it does not cause any harm to the environment. From previous research, the flow rate of the coolant has an influence on the tool life when using flood coolant as cutting fluid. Higher flow rate leads to longer tool life [14]. In the case of flood coolant machining, the tool is constantly cooled by the coolant along with heat generated due to friction.

Minimum Quantity Lubricant (MQL) is one of the technique, by spraying a very tiny particle of lubricant to the cutting zone [14–18]. Many reports revealed that MQL capable to increase cutting tool life and surface finish [19–21]. Other factor that contributes to improvement of machinability is cutting tool geometries. Major improvement has been made on the helix angle and pitch angle in order to prolong its cutting tool life [22, 23]. Therefore, the objective of this research is to study the effect of various coolant strategies and end mill geometries on machinability of Inconel 718.

2 Methodology

2.1 Machining Parameters

In this project, the end milling process was conducted on a MAZAK Nexus 410A-II Vertical Milling CNC. The value of cutting speed, feed rate, axial depth and radial depth were kept constant. Table 1 tabulated the overall machining parameters. Two types of square end mill, consists of diameter Ø 6 mm, 4 flutes, same helix angle but different pitch angle, rake angle and carbide material are used in this experiment. Tables 2 and 3 show the cutting tools geometries. Workpiece with a size of 72 mm × 15 mm × 10 mm was mounted on a jig and dynamometer as shown in Fig. 1. Both cutting tools undergoes same experiment, which are flood cooling and MQL. Table 4 shows the cooling techniques parameters. During the experiment, cutting force, cutting temperature and tool life were measured. The measuring instrument such as

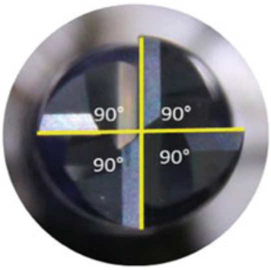
Table 1 Machining parameters

Parameters	Levels
Cooling techniques	Flood and MQL
Cutting speed, V_c (m/min)	70
Feed, f (mm/tooth)	0.05
Axial depth of cut, a_p (mm)	4
Radial depth of cut, a_e (mm)	0.5
Milling technique	Side milling (finishing)

Table 2 Cutting tool geometry

Cutting tools	Parameters	Levels
Cutting tool 1 (T1)	Number of flutes	4
	Tool overhang, (mm)	25
	Pitch angle, θ (°)	87/93
	Helix angle, θ (°)	40
	Carbide material	Micro-fine grain
Cutting tool 2 (T2)	Number of flutes	4
	Tool overhang, (mm)	25
	Pitch angle, θ (°)	90/90
	Helix angle, θ (°)	40
	Carbide material	Micro-grain

Table 3 Helix and pitch angles of cutting tools

dynamometer and tool maker microscope are set up prior the experiment to measure the cutting force and tool wear, respectively.

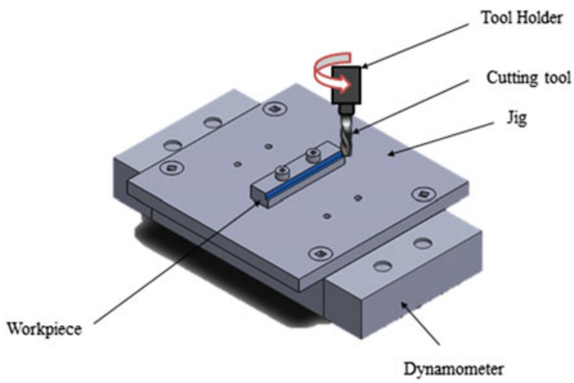


Fig. 1 Preparation jig and work-piece setup

Table 4 Cooling techniques parameters

Cooling technique	Parameters	Levels
MQL	Input Pressure, *P* (Mpa)	0.4
	Nozzle distance, N_d (mm)	8
	Nozzle angle, θ (°)	45
	Lubricant type	Synthesis ester
Flood coolant	Discharge volume, *Q* (ℓ/min)	24.16
	Discharge pressure, *P* (MPa)	1.5
	Lubricant type	Semi-synthetic (SYN 2188)

3 Results and Discussion

3.1 Cutting Force

Figure 2 shows the result of resultant force at various tool geometries and cooling techniques. From the results, it was observed that T1 under flood cooling experience the highest resultant force compare to T2 for both cooling techniques. According to [24], the lubrication effect of MQL reduces the friction between tool and work piece interfaces thus reducing the cutting force. For comparison tools geometries at flood coolant condition, T2 shows the resultant force is reduced by 28.69% compared to T1. From the previous study by [25], different pitch angle enhance the stability of milling process when spindle speeds are lower. Comparison of tool geometries under MQL condition, T2 recorded a decrement by 32.36% compared to T1. According to [26], high rake angle with modest chamber and medium edge gives equal or lowest

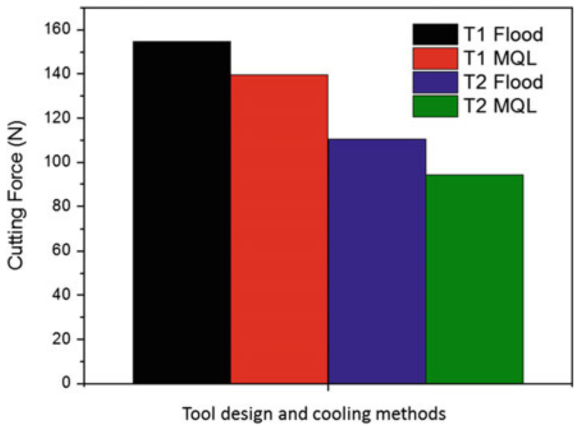


Fig. 2 Result of resultant force

vibration. In addition, increasing rake angle with sharp cutting edge reduces the cutting force.

3.2 Volume Material Removed and Tool Life

As an illustrated in Fig. 3, T1 and T2 under MQL condition recorded the highest volume material removed (VMR), 18,000 mm^3 at 9000 mm cutting distance and tool life of 57 min. Meanwhile, T2 under flood cooling technique recorded the VMR of 16,500 mm^3 at 8250 mm cutting distance and tool life of 52.3 min. As a comparison,

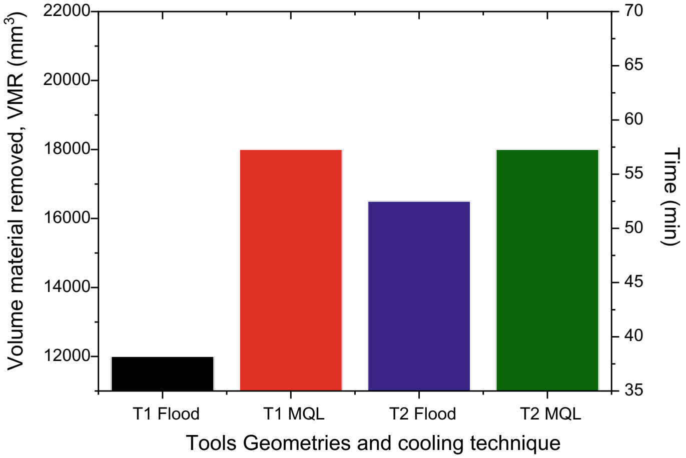


Fig. 3 Tool geometries and cooling methods against volume material removed

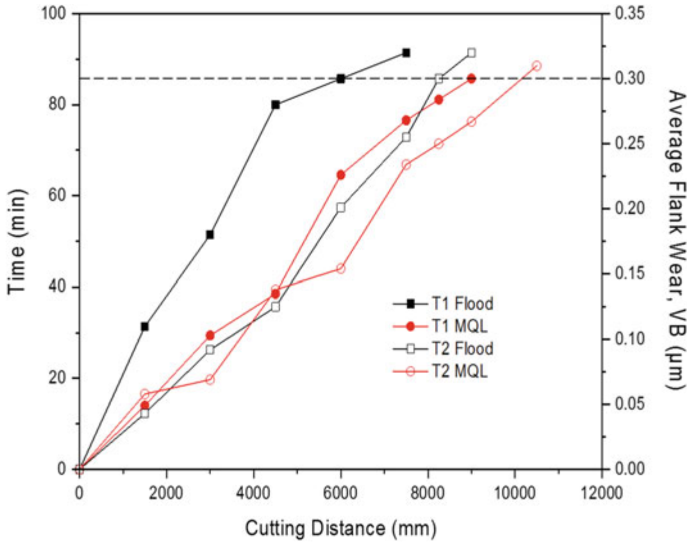


Fig. 4 Tool life progression

T1 recorded the lowest VMR under flood condition, recorded 12,000 mm^3 at cutting distance of 6000 mm and tool life of 38 min.

Figure 4 shows the result of cutting tool life progression under various cutting tool geometries and coolant techniques. From the result, it shows that T1 under flood condition, it experienced low flank wear rate, which is 0.110 mm at 1500 mm cutting distance. As the machining process continues, flank wear and chipping were increased due to higher temperature was generated during machining process. At 6000 mm cutting distance, cutting tool reached tool life criteria value, which is average flank wear is exceeding 0.3 mm. According to ISO 8688-2, the tool is consider to achieve its life. At this condition, it recorded the lowest VMR of 12,000 mm^3 and tool life of 38 min. While the longest tool life and cutting distance is obtained when using T2 under MQL condition MQL condition attributed low friction force at cutting tool due to cooling and lubrication performance, which can reduce tool wear rate and extend tool life compared to dry machining [24, 27–29]. Among all experiment, T2 under MQL condition has achieved the highest cutting distance (9000 mm) and cutting time (57 min). Most of the cutting tools suffered from severe flank wear and chipping. It is due to generation of high cutting temperature due to insufficient cooling.

4 Summary

In this study, Minimum Quantity Lubricant (MQL) shows the most effective cooling technique compared to flood cooling. Based on the results, it is proven that MQL condition provide sufficient lubricant to the cutting region and lower the friction force between tool and work piece compared to flood cooling. In term of resultant force, T2 under MQL condition able to reduced resultant force by 32.36% compared to T1. While for tool life, T2 under MQL condition achieved the longest cutting distance and cutting time compared to flood cooling.

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