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EFFECT OF COOLING METHOD ON HIGH-SPEED MACHINING INCONEL 718

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ABSTRACT

Due to its exceptional characteristics, which result in high cutting temperatures during a high-speed machining process, Inconel 718 is well known as a difficult-to-cut material. To overcome this matter, proper cooling method is important to be considered as it influences the cutting results. Advance cooling approach such as minimum quantity lubrication (MQL), nano-MQL and cryogenic are identified as approaches that implemented on high-speed machining of Inconel 718 using uncoated carbide tools. All approach improved the cutting tool life compared to conventional method, from 48 minutes to 60 minutes and 48 seconds until 80 minutes machining time. The cutting force are still desirable, as well as resultant surface roughness. Nano-mql of 0.05% hBN weight percentage proves as the promising approach that can be implemented during milling Inconel 718.

KEYWORD

High-speed machining, Inconel 718, MQL, Hexagonal boron nitride, Cold air

INTRODUCTION

Nickel superalloy has been extensively used in many industries such as aerospace, nuclear power plants, petrochemical plants and others. High yield strength of approximately 700-1200 MPa (retained up to 750 °C), high fatigue strength, high ultimate tensile strength (900-1600 MPa, maintained mechanical properties within wide range temperature and good creep resistance are the unique attractiveness characteristics of this alloy (Ezugwu and Musfirah et al, 2015).

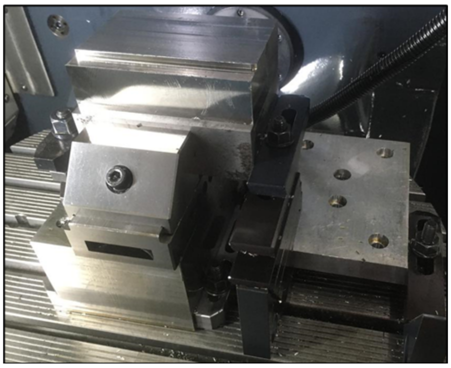
Due to their exceptional qualities and metallurgical traits, they are among the hardest materials to process. This particular alloy can withstand at high temperatures, which results in plastic deformation and tool failure, particularly in the cutting zone area. Abrasive wear, diffusion wear, welding/adhesion of workpiece material produced built-up edge (BUE), and poor heat conductivity were frequent causes of tool failure (Jawaid et al, 2001). It is worse when high-speed machining is implemented.

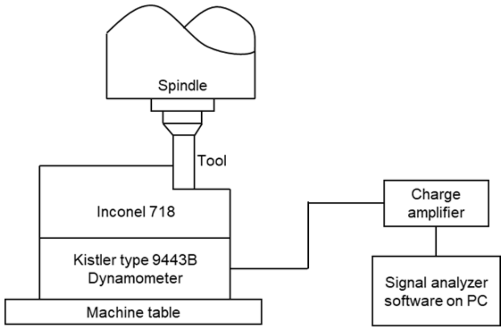
In order to overcome these problems, proper cooling is important in order to reduce the cutting temperature. Previous researchers (Gupta et al., 2015) found that the application of cooling technique is the most noticeable factor which influence the cutting process. Conventional or flood coolant is the common application but since it is high in cost and environmental and health hazards, near-dry-machining (NDM) approach is more desirable. Previous researchers (Sohrabpoor et al., 2015) had implemented NDM in their works and it proves that this approach produce better results compared to conventional method.

MATERIAL AND METHODOLOGY

A rectangular Inconel 718 with the dimension of 100 mm x 100 mm x 150 mm chosen as the workpiece. Uncoated carbide inserts were used as cutting tools which manufactured by SECO. The insert type is XOEX10T308FR-E05 and the tool holder model number is R217.69-1616.3-10-2A with a diameter of 16 mm, a maximum ramp angle is 7.5° and two inserts can be installed on the holder.

DMG Mori DMU 50 series 5-axis CNC machine had been selected for this work. It is equipped with a 630 mm table diameter and 300 kg maximum load, 80 to 18,000 rpm of spindle speed range, a 14 kW motor drive, and an internal cooling system. A Kistler dynamometer type 9443B was mounted on the machine table for cutting forces measurement which were later analyzed through the software. The workpiece was secured on the dynamometer using a specially designed fixture and the experimental setup along with a schematic diagram, shown in Figure 1.


(a)



(b)

Figure 1: (a) Experimental setup, (b) Schematic diagram of experimental setup

Microvisual XOPTRON XST150 microscope being used as device for observing and measuring the tool wear. It has a zoom ratio of 12.5:1 and a magnification from 8 until 100 times. Tool rejection criteria or failure criteria were according to: (a) average non-uniform flank wear ≥ 0.2 mm, (b) maximum flank wear ≥ 0.2 mm on any individual tooth, (c) excessive chipping/flaking or catastrophic failure of the cutting edge, whichever occurred first as applied by other researchers [13-15]. The selected parameters being selected after being optimized in previous works.

RESULT AND DISCUSSION

Table 1 listed the results obtained from the experimental works that had been conducted. Through flood coolant, the tool can sustain up to 48 minutes of machining time before it being rejected at 0.23 mm with 741.99 N cutting force and 0.2µm roughness. By applying palm oil through minimum quantity lubrication method (MQL), the tool life prolonged until 78 minutes and 48 seconds. As expected, the advance cooling strategies enhance the machining of Inconel 718. The tool life was prolonged to 60 minutes and 48 seconds by cold air approach while 68 minutes and 48 seconds, 72 minutes and 80 minutes was recorded by mixture of palm oil and hexagonal boron nitride (hBN) as the nano additives at 0.15%, 0.10% and 0.05% weight percentage, denoted by NPO3, NPO2 and NPO1 respectively. This was evidence that shows these strategies were effective and the lubricant able to reduce the friction at the sliding surfaces.

Table 1 Different cooling strategies results

Lubrication method	**Cutting time**	**Cutting force, F (N)**	**Surface roughness, R (µm)**			**Tool wear (mm)**	
			Entry	**Exit**	**Avg**	**Tool 1**	**Tool 2**
Flood	48 min	741.99	0.200	0.200	0.200	0.23	0.21
MQL (PO)	78 min 48 sec	816.73	0.193	0.178	0.186	0.21	0.19
NPO1	80 min	821.73	0.160	0.282	0.221	0.21	0.20
NPO2	72 min	874.01	0.254	0.215	0.235	0.21	0.22
NPO3	68 min 48 sec	876.87	0.202	0.324	0.263	0.22	0.21
Cold air	60 min 48 sec	901.30	0.181	0.213	0.197	0.2	0.19

It can be seen in Figure 2, in overall cutting forces produced by all strategies are increasing. Palm oil, NPO1, NPO2, NPO3 and cold air recorded increment of 10.07%, 10.75%, 17.79%, 18.18% and 21.47% respectively. The pattern is as expected for nano-lubricant where NPO1 produced lowest cutting force at 821.73 N, followed by NPO2 at 874.01 N and the highest NPO3 at 876.87 N. This is mainly due to the flank wear width whereas the cutting time increased, the tool edges became blunt, results in higher friction coefficient and more contact area at the tool/chip interface is generated.

Most of the wear gradually increase with respect to the cutting time and its wear mechanism can be clearly seen through other coolant strategies (Figure 3). At the end of tool life for PO, burn marks below the wear region can be observed.

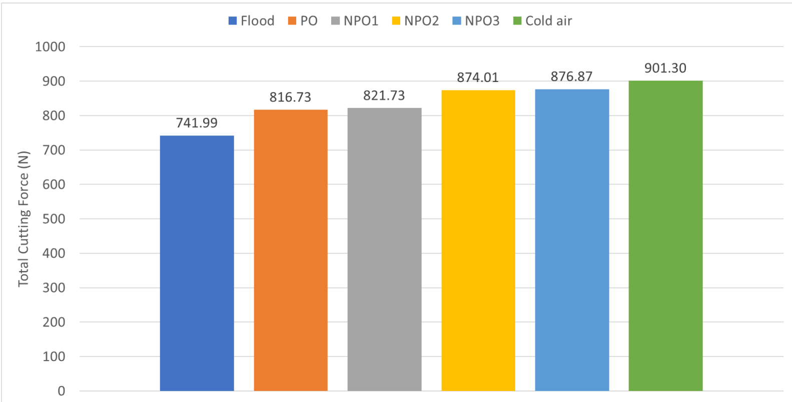


Figure 2: Total cutting force of different cooling strategies

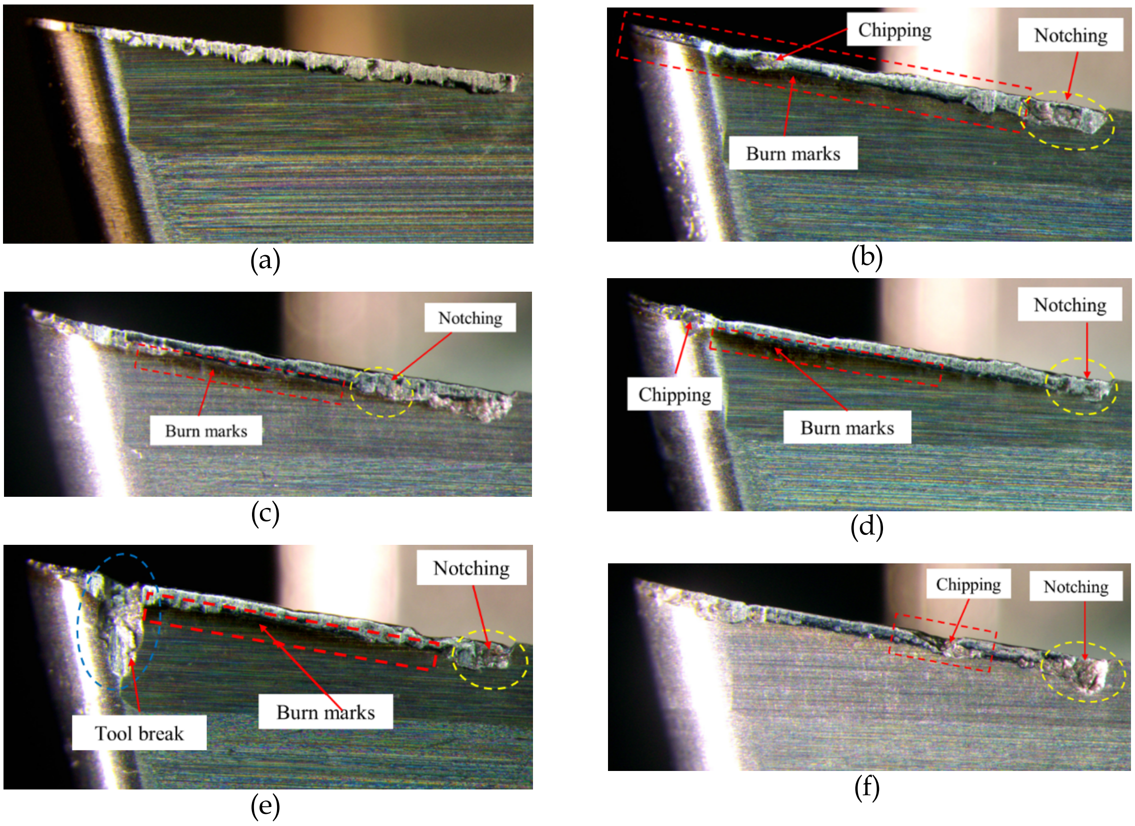


Figure 3: Wear mechanism of cutting tool using different cooling strategies; (a) flood, (b) PO, (c) NPO1, (d) NPO2, (e) NPO3, (f) cold air

This is due to the high temperature generated while machining work which led to high cutting force. However, the cooling agent, palm oil manages to prevent the excessive friction from further damaging the tool surface and formed abrasive wear. Interestingly, cold air approach manages to completely dissipate the excessive heat during the machining where no burn marks observed near the wear region. Despite of that, chipping and notching encountered at the wear region quite severe if compared to others. This shows that even though the high friction heat being effectively remove, the tool become more brittle due to the extreme cold air. Without any lubrication, the tool material being adhered to the chips and can't be flushed away, thus fail at early stage.

CONCLUSION

In conclusion, NDM approach shows promising machining results as it improved the tool life, desirable cutting force and some of it produced better surface finish. From this recent work, it can be stated that the most desirable approach that can be implemented in high-speed machining Inconel 718 is minimum quantity lubrication using mixture of palm oil and hBN at 0.05% weight. The tool sustained until 80 minutes of cutting time with only 10% cutting force increment and better surface finish on the workpiece.

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