A Review on Influence of Cutting Fluid on Improving the Machinability of Inconel 718

Prajith Sivadasan, Gotimayum Sachidev Sharma, Ivan Sunit Rout, and P. Pal Pandian

Abstract Nickel-based superalloys are widely used in the production and manufacturing sectors that require processes or applications that endure or operate at very high superheating temperatures. With the properties of high tensile strength, high melting point, and lightweight structural arrangement of molecules within the alloy material composition makes it more suitable for industrial utilization in aerospace industries and marine applications. This review paper discusses the use of various coolant lubricants that improves the machinability of Inconel 718 based on parameters such as surface roughness and tool wear under the influence of cutting speed, feed rate, and depth of cut. The machine used for analysis is CNC milling machine which will be used for experimentation using ceramic inserts as end milling tool. Various cooling techniques such as hybrid cooling, flood emulsion cooling, minimum quantity lubrication, and cryogenic cooling are being summarized in this paper from various experimentations and conclusions of other authors. On the basis of review, the hybrid cooling technique is found to be better than other cooling techniques because of its ability to obtain long tool life and smoother surface finish on the workpiece. With the use of these reviewed data, further research for finding a more compatible and effective cooling lubricant has to be done by experimentation in order to obtain an improved machining process for Inconel 718 material.

Keywords Ceramic inserts · CNC milling machine · Inconel 718 · Flank surface · Rake surface

1 Introduction

Superalloy materials are predominantly used in manufacturing and engineering construction sectors involved in applications for energy supply. The most common type of superalloys used is nickel-based superalloys. Inconel 718 is a nickel-based superalloy that is most commonly used in aerospace and turbine industries. This

P. Sivadasan · G. S. Sharma · I. S. Rout (✉) · P. Pal Pandian
CHRIST (Deemed to be University), Bangalore, India
e-mail: ivan.rout@christuniversity.in

A. Praveen Kumar et al. (eds.), *Advances in Lightweight Materials and Structures*, Springer Proceedings in Materials 8, https://doi.org/10.1007/978-981-15-7827-4_50

alloy is mostly used in the blades of turbine engines and in the nose of aircraft body due to its high temperature resistance, high strength compared to weight, and high tensile strength. Due to it high melting point characteristic, it is used in superheating applications that require materials to withstand at high temperatures.

With the integration of the stated properties, these materials are hard to machine continuously for longer periods of time, and hence, require periodic changing of machining tool due to wear. This, in turn, creates a manufacturing downtime and costs in major industries and production factories due to constant machine breakdown or repair. In order to overcome this problem and achieve efficiency in machining process, research and study are being done on developing new tools and coated materials, and parameter optimization using various lubrication techniques such as cryogenic lubrication, flood lubrication, hybrid lubrication, and liquid nitrogen lubrication. [1].

According to Zhuang et al. [2], cutting fluids provide an effectual way in improving machining of hard-to-machine materials by reducing friction developed at the cutting contact area through effective lubrication that reduces the temperature at the machining zone due to cooling by convectional heat transfer, and hence, reduces tool wear which, in turn, provides improved surface finish [2].

According to Kaynak et al. [3], cutting fluids used in lubrication of machining process contain many harmful chemicals that are difficult to discard and recycle in the environment, also causing skin and lung disease to the operators. Due to strict environment laws, there is less flexibility in using cutting fluids, although various substituent formulants that does not include lead, sulfur, or chloride are made, and they are not yet achieved to be completely harmful. The total incurred costs regarding the usage of cutting fluids are approximated to be several billions per year [3].

Hence, there is a need for an effective and cost-efficient cutting fluid in the industrial market sector associated with environmental and economic impacts. This review is done to find out various suitable cutting fluids and techniques that meet required industrial environmental and economic standards, for effective machining of Inconel 718 material using ceramic inserts and CNC end milling machine as the basis for study, also to obtain longer tool life and smooth surface finish in accordance with various operating parameters.

2 Cooling Techniques

Studies have been done on various cooling techniques for improving the machining of Inconel 718. These techniques depend on economic and technical factors with respect to the machining process in various applications. Technical factors refer to the availability of particular cooling equipment during the machining process such as availability of a particular number of nozzles, nozzle diameter, pressure regulator, and so on. Industries and production units select the techniques for lubrication based on the manufacturing process and cost factors while fabricating or machining the components for the desired end product. Various cooling techniques based on recent research developments include hybrid cooling, cryogenic cooling, flood cooling,

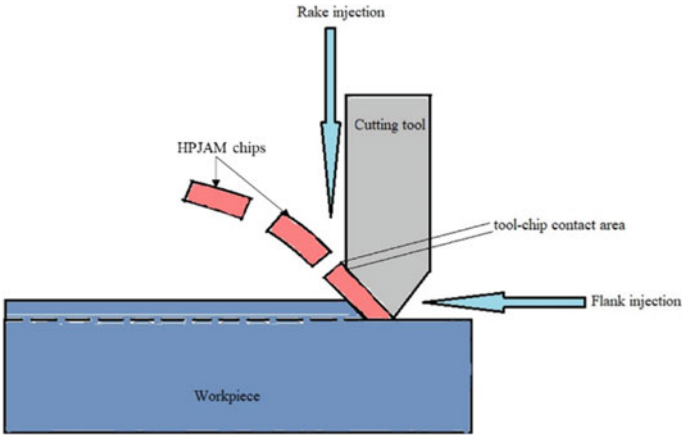

Fig. 1 Flank and rake injection of cooling lubricant in HPJAM

minimum quantity lubrication, and high-pressure jet assisted machining (HPJAM). According to Shokrani et al. [4], injection of pressurized fluid on the tool flank and rake surface provided less surface hardness with 10–15% decrease in overall machining force, and hence, obtained results with less surface defects in comparison with flood cooling [4], which provided less surface smoothness due to inability of the lubricant to reach the tool workpiece and chip interface creating a heat transfer barrier (Fig. 1).

Similarly, there exist other techniques that provide high production rate and optimum surface finish. In hybrid cooling, a cryogenic setup for spraying liquid nitrogen at the cut zone, in addition with simultaneously spraying pure rapeseed oil for coating the cold tool periodically was found to be effective in improving tool wear without much change in the surface roughness produced, regardless of the change in technique used. The tool life in hybrid cooling technique was found to be 50% greater than MQL, and 33% greater than cryogenic technique [5]. From experimentational studies, inclination of two jets in the direction of rake face and flank face of the machine tool was determined to be the most effective configuration in machining [6].

The experimentation conducted by Chopra et al. [7] determined flood cooling using emulsion-based oil provided better surface finish for shorter life when compared to cryogenic cooling using liquid nitrogen [7]. The cryogenic cooling technique provided best tool life and good surface finish after long machining duration, when compared to other techniques such as dry machining, flood emulsion, and blowing of cold air as a coolant as shown in Fig. 2.

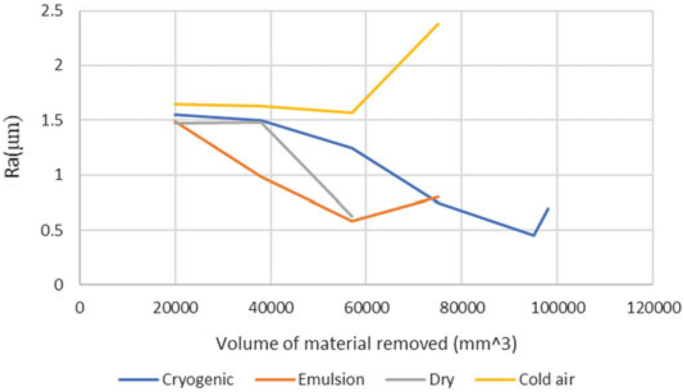

Fig. 2 Comparison of various lubrication methods on the basis of surface hardness and material removed

3 Parametric Observations

From Table 1, it can be observed that average cutting speeds used in most experimentations ranges from 30 to 140 m/min, with maximum feed rates up to 0.2 mm/rev. The maximum pressure ranges from 5 to 200 bars. Most of the tool inserts used were made up of coated carbide or ceramic material [8], and the lubricants used mostly included emulsifiers that mostly contain base oil as vegetable oils, along with intermittent use of liquid nitrogen in various experimentations. Higher cutting speeds were observed for ceramic tools and emulsifier lubricants (Figs. 3 and 4).

4 Analytical Study

Emulsified oils such as palm oil mixed with water had higher viscosity compared to synthetic esters. Hence, the lubrication during machining was improved as friction was reduced due to increase in viscosity. Oil–water ratio affects tool life under minimum quantity lubrication. Greater oil content in fluids leads to poor fluidness. Usage of emulsified oils, namely, palm oil and rapeseed oil improve the performance and deposition of lubrication film on the surface of tool or workpiece, due to the presence of greater amount of unsaturated fatty acids in the carbon chain [9]. Use of liquid nitrogen in cryogenic cooling or minimum quantity lubrication provides effective lubrication [10], but these lubricants are difficult to dispose in the environment because of the presence of harmful chemicals present in its chemical composition, and hence, contributes to global warming, skin and lung associated diseases to the operators present in the industrial environment after periodic exposure to nitrogen gas for long durations. Hence, these types of coolants provide less safe working conditions comparatively to other existing coolants. However, they can be used in

Table 1 List of studies on effective lubrication parameters

Authors	Cutting speed (m/min)	Feed rate	Flow rate	Surface roughness, Ra (μm)	Tool/tool life	Min pressure (bar)	Max pressure (bar)	Lubricant
Aziz Ul Hassan Mohsan et al.	140	–	10 L/min	Rz = 3, Rq = 0.4	Triple coated carbide	150	200	Eccoocool emulsifier, 10% conc
D.Fernańdez et al.	50	0.25 mm/rev	–	0.45	Precoated carbide tool/30.60 min	–	–	Liquid nitrogen
Yunn-Shiuan Liao et al.	60	0.1 mm/tooth	60 ml/hr	–	Coated carbide	5	5	BESOL 25
E. O Ezugwa et al.	250	0.2 mm/rev	5 L/min	–	Whisker reinforced ceramic	–	150	Emulsions of alkanolamine salts and di-cyclohexylamine
Alborz Shokrani et al.	140	–	15 kg/hr	0.4	Solid tungsten carbide	–	5	Liquid nitrogen and pure rapeseed oil
D. G Thakur et al.	40	0.08 mm/rev	10 ml/hr	–	Tungsten carbide	–	130	Water soluble cutting oil (20:1)
Erween Abd Rahim et al.	30	0.05 mm/rev	–	–	Coated carbide/90 s	–	–	Palm oil
Venkat Pradeep Allu et al.	70	–	0.6 kg/min	–	Multi-layered coated carbide	–	–	Oil and liquid nitrogen

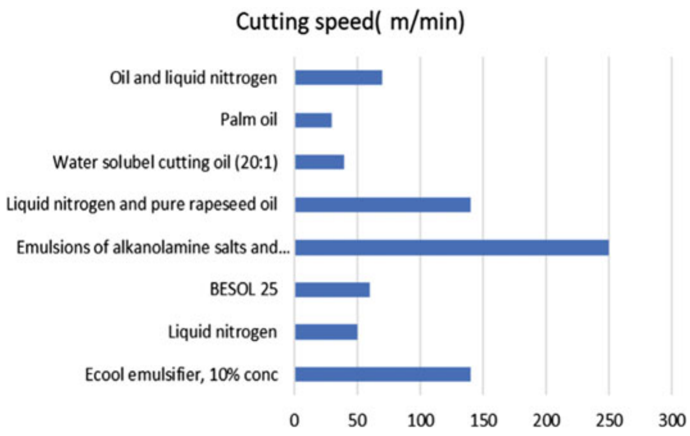

Fig. 3 Comparison of lubricants and cutting speed

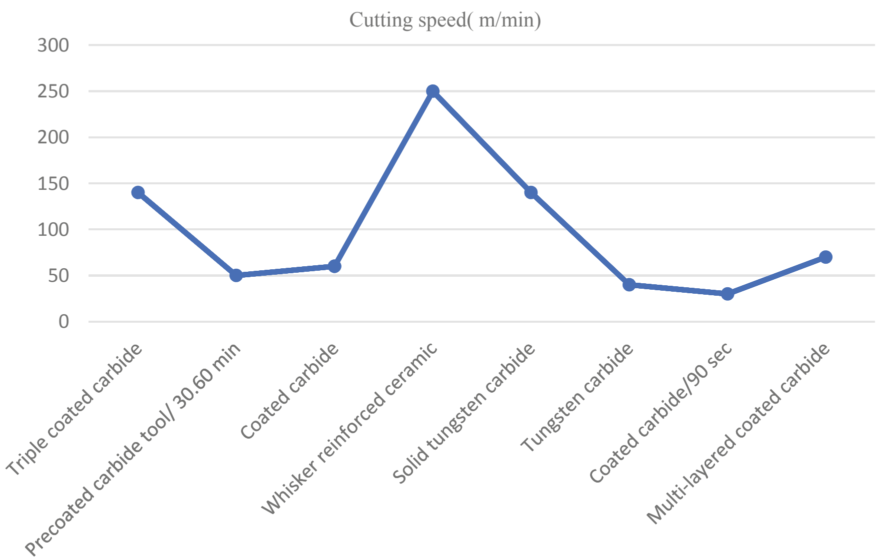

Fig. 4 Comparison of tool inserts and cutting speed

prescribed amounts as per industrial and environmental standards along with other coolants. According to Rout et al. [11], optimized cutting parameters for improving tool life under minimum quantity lubrication involve lower cutting speeds, less feed rates, and greater quantity of lubrication directed along an inclined axis [11]. As per experimentation conducted by Kaynak et al. [3], optimum and effective oil–water ratio and flow rate of fluid under minimum quantity lubrication are 60:40 and 60 ml/h, on the basis of observations from rake face wear of the tool.

5 Conclusion and Future Scope

Hybrid cooling and high-pressure jet assisted machining are the recent developments in cooling techniques that proved to be effective using combination of more than one property, or by varying external cooling environmental factors. These methods require an additional specifically designed equipment for operation. Among other already existing cooling techniques, cryogenic cooling was observed to provide longer tool life and smooth surface finish after long machining duration [7], whereas flood cooling provides better lubrication and smooth surface finish at lower cutting speeds. At higher cutting speeds, flood cooling provided optimum surface finish and shorter tool life, due to the developmental effect of heat exchange barrier of lubricant present between the workpiece material or cutting tool [12]. Emulsified oils exhibited comparable properties of lubrication to that of synthetic ester and gaseous fluids during machining operation. Emulsified oils tend to cause less harmful effects during machining process, and hence, it is considered to be a viable alternative.

With the use of these reviewed data, research has to be done for finding eco-friendly compatible coolants that improve the machinability of Inconel 718, and machining tool life by using the most appropriate methodology of lubrication.

References

1. Akhtar W, Sun J, Sun P, Chen W, Saleem Z (2014) Front Mech Engg 9: 106
2. Zhuang K, Zhang X, Zhu D, Ding H (2015) Employing preheating- and cooling-assisted technologies in machining of Inconel 718 with ceramic cutting tools: towards reducing tool wear and improving surface integrity. Int J Adv Manuf Technol 80:815–1822
3. Kaynak Y (2014) Evaluation of machining performance in cryogenic machining of Inconel 718 and comparison with dry and MQL machining. Int J Adv Manuf Technol 72:919–933
4. Shokrani A, Dhokia V, Newman ST (2017) Hybrid cooling and lubricating technology for CNC milling of Inconel 718 nickel alloy. In: 27th international conference on flexible automation and intelligent manufacturing, vol 11, pp 625–632
5. Shokrani A, Newman ST (2018) Hybrid cooling and lubricating technology for CNC milling of Inconel 718 nickel alloy. In: Procedia CIRP 77, 8th CIRP conference on high performance cutting (HPC 2018), pp 215–218
6. Pusave, F, Kramar D, Krajnik P, Kopac J (2010) Transitioning to sustainable production—part II: evaluation of sustainable machining technologies. J Cleaner Prod: 1–11
7. Chopra SA, Sargade VG (2015) Metallurgy behind the cryogenic treatment of cutting tools: an overview. In: 4th international conference on materials processing and characterization, vol 2, pp 1814–1824
8. Rout IS, Pandian PP (2018) Selection of cutting parameters for the machinability of Inconel using grey relational analysis. In: MATEC web of conferences, vol 172, p 04004
9. Abd Rahim E, Sasahara H (2017) Performance of palm oil as a biobased machining lubricant when drilling inconel 718. MATEC Web Conf 101:1–5
10. Nadig DS, Satisha GV (2012) Effect of cryotreatment on the wear performance of tungsten carbide tools. Ind J Cryogenics 137(1–4): 188–193

11. Rout IS, Pandian PP, Raj A, Lobo Ivan KC, Antony S (2020) Parametric investigation on the tool wear while performing face milling on Inconel 718 using round insert. Int J Mech Prod Eng Res Dev 10: 1–11
12. Rout IS, Pandian PP (2018) A Review on parametric study of hard machining of Inconel 718 using coated carbide tool. Adv Sci Eng Med 10: pp 234–239