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Hybrid cooling and lubricating technology for CNC milling of Inconel 718 nickel alloy

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Abstract

Inconel 718 is widely used in aerospace, marine, oil and gas and gas turbine industries due to its unique material properties. These material properties such high strength, high hardness and high hot hardness have also made Inconel 718 a difficult to machine material. Machining Inconel 718 is associated with poor tool life and surface integrity resulting in high manufacturing costs and low productivity. Minimum quantity lubricant (MQL) and cryogenic machining are alternative cooling/lubricating techniques for improving machinability of difficult to machine materials. However, their application is limited in machining Inconel and most studies are concentrated on turning. In this paper, MQL, cryogenic cooling and a novel hybrid cryogenic and MQL (CryoMQL) cooling technique are used for CNC milling of age hardened Inconel 718. The analysis indicated that using the proposed hybrid CryoMQL cooling/lubricating system can almost double the tool life and improves surface roughness by 18% resulting in significant improvement in machinability of Inconel 718.

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Keywords: Cryogenic machining; Inconel 718; Hybrid cooling; minimum quantity lubricant; MQL

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1. Introduction

Inconel 718 is a heat resistant nickel alloy which is extensively used in aerospace, gas turbine, oil and gas and marine industries. Its ability to maintain its mechanical properties at elevated temperatures, high strength and hardness and excellent wear and corrosion resistance have made Inconel 718 an attractive material for harsh operational environments [1].

Owing to its austenitic microstructure, strain hardening is a major issue when machining Inconel 718 [2]. High material toughness and strain hardening properties together with high chemical affinity to most cutting tool materials have notoriously made Inconel 718 a difficult-to-machine material [3, 4]. High material toughness and hardness results in chipping of the cutting tools whilst the existence of hard carbide particles in the material rapidly wears the flank face of the cutting tools. The Inconel's tendency to weld onto the cutting tools results in crater wear during machining weakening the cutting edge and resulting in notching wear [2, 4, 5]. It is well established that a significant portion of the cutting energy is transformed into heat at the cutting zone. The poor thermal conductivity of Inconel 718 (11.4 W/m-K) results in heat accumulation at the cutting zone and particularly on the cutting tool's rake face further exacerbating crater wear [5].

Considerable attempts have been made by various researchers to improve the machinability of Inconel 718. This ranges from laser assisted machining [6-8] and ultrasonic assisted machining [9-11] to using innovative cooling/lubricating techniques such as minimum quantity lubricant (MQL) [12, 13] and cryogenic machining [14, 15].

Rahman et al. [3] studied the effect of various machining parameters on machinability of Inconel 718 in turning operations. They noted that increasing feed rate and cutting speed has a detrimental effect on tool life measured in minutes. Polvorosa et al. [16] compared the effect of high pressure (80 bar) coolant with conventional coolant (6 bar) in turning Inconel 718. The investigations revealed that employing high pressure coolant can reduce crater wear on tungsten carbide inserted tools. Moreover, it was found that using high pressure coolant reduces the flank wear growth rate when compared with conventional flood cooling. Based on the experimental results, adhesion wear and notch wear were dominant in both conditions whilst notch wear was more profound when using high pressure coolant.

Due to the environmental concerns and increasing costs of maintenance and disposal of cutting fluids, using MQL as an alternative cooling and lubricating method in machining has gained more attention. In this method, a small amount of lubricant (10-100 ml/hr) is sprayed into the cutting zone in a stream of pressurized air (4-6 bar). A study [12] on milling Inconel 718 found that when using water-miscible coolant-lubricants for MQL, the flow rate of the coolant-lubricant has a more profound effect on machinability than the water/oil ratio of the coolant-lubricant. Generally, it was reported that increasing the flow rate and oil percentage reduce the tool wear when machining Inconel 718. The authors also noted that the effect of MQL flowrate on reducing tool wear significantly reduces after 60 ml/hr flow rate. Kamata and Obikawa [13] compared MQL with dry and flood cooling in high speed turning of Inconel 718. They found that when using Ti/AlN superlattice and TiAlN coatings, MQL outperforms conventional dry and flood cooling in terms of tool life and surface roughness. The authors also investigated the effect of MQL carrier gas on tool life. They noticed that air is a better carrier gas than argon and attributed this to the lower specific heat of argon as compared to air.

Another alternative to conventional cooling-lubricating in machining operations is cryogenic cooling using liquefied gases. In this method, termed cryogenic machining, liquefied gases such as nitrogen and helium are used to cool the workpiece material, cutting tool or both workpiece and cutting tool materials [17]. It has been reported that temperatures as low as -196ºC can favourably alter material properties of both cutting tool and workpiece and improve machinability [18]. Wang and Rajurkar [19] developed a cryogenic cooling system to freeze the cutting tool during turning operations as a method for removing heat from the cutting zone. They reported that using cryogenic cooling reduced tool wear in turning Inconel 718 and tantalum. Kaynak [20] studied the effect of cryogenic cooling in turning Inconel 718 and found that cryogenic cooling reduces tool flank wear compared to dry and MQL. However, the effectiveness of cryogenic cooling did not extend to notch wear and almost identical wear was observed for all machining environments. Shokrani et al. [14] conducted a feasibility study on cryogenic milling of Inconel 718 and concluded that cryogenic cooling has the potential to reduce surface roughness as compared with conventional dry and flood cooling. Furthermore, the authors noted that all tools suffered catastrophic tool failure