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Research Paper

A comparative study of recent lubri-coolant strategies for turning of Ni-based superalloy

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ABSTRACT

This paper deals with a comparative study of High-pressure jet, cryogenic, minimum quantity lubrication and minimum quantity lubrication with nanofluid cutting environments during machining of Inconel 718 superalloy. Inconel 718 has been chosen for this study because of its wide applications in spacecraft, defense, and energy sectors. The important machining process parameters such as speed, feed, and rake angle have been chosen and their different levels have been used based on tool-work combination. Cutting force, flank wear and surface finish have been analyzed. Additionally, surface defects, surface topography, residual stress on the machined surface and chip morphology have been studied. The results show that the cryogenic environment results in better surface integrity and reduced tool wear during machining of Inconel 718.

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1. Introduction

Ni-based superalloy has become an attractive material for manufacturing of many critical components. Thakur and Gangopadhyay [1] reported Ni-based superalloys contribute nearly half of the total weight of an aero engine. Ni-based superalloys have high rupture strength, creep strength, corrosion, and oxidation resistance [2]. It also has high cyclic fatigue strength and the capability to maintain high strength even at elevated temperature (possesses yield strength above 1000 MPa at 600 °C). Due to these unique properties, the Ni-based superalloys have been used in manufacturing of the aeronautical engines, gas turbines, nuclear and petrochemical applications which involve static as well as cyclic loading at elevated temperature. Also, it has excellent ductility even at cryogenic temperature mainly due to its face centered cubic (FCC) lattice structure, and hence, it has been used in rocket motor casing, cryogenic tank and superconducting structural components [2].

The machining process is a secondary manufacturing process which is widely adopted to provide appropriate shape and dimension to various engineering and structural materials. Worldwide demand for the machined components is growing every year. This is because of a substantial growth in machining industries which are capable of producing high precision components with excellent surface finish. However, not all materials can be easily machined because of their chemical, mechanical and thermal properties. These materials are called difficult to machine materials. Inconel 718 is considered as one of the difficult to machine material because of its high yield strength, high strain hardening, poor thermal properties, and high chemical affinity. The poor machinability of Inconel 718 is attributed to work hardening during machining process and also due to the presence of hard carbides in its microstructure. It possesses unusually high dynamic shear strength and poor thermal property which lead to increase cutting temperature during the machining process [2]. The high chemical affinity of this alloy with most of the tool materials results in large diffusion wear on the cutting tool, which further leads to the formation of built-up edge (BUE) [2]. Rahman et al. [3] experimentally studied the effect of cutting conditions and cutting geometry on tool life in turning of Inconel 718. The tool life got reduced with an increase in feed and speed. It was also reported that work hardening during turning depends upon the magnitude of feed and cutting speed used during the machining process [4]. Different simultaneously acting wear mechanisms resulted in high rate of tool wear during dry cutting of Inconel 718. The high rate of tool wear reduces production rate and drastically increases manufactured component costs. Hence, it is important to enhance the machinability characteristics such as cutting forces, tool wear, and surface finish for the Inconel alloys.

For machinability rating (MR), SAE 1020 grade steel (free cutting steel) is considered as a reference having MR of 100 on a scale of 100. Ni-based superalloys have been assigned the MR of less than 25 whereas wrought Inconel 718 has been rated as 14. Despite having very low MR, 35% of the total manufacturing cost is utilized

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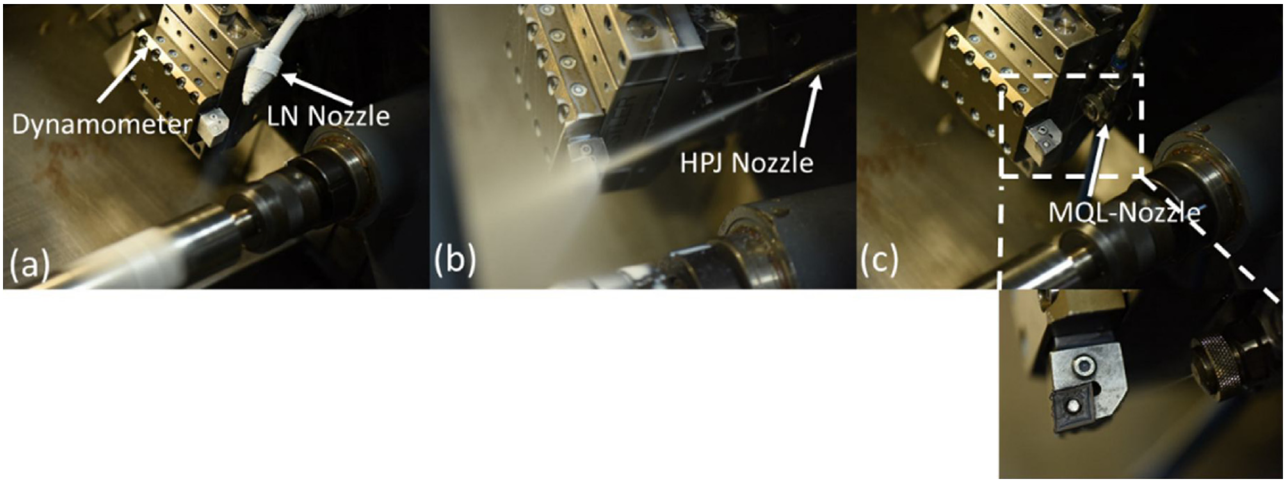

Fig. 1. Experimental set-up (a) Cryogenic (b) HPJ, and (c) MQL.

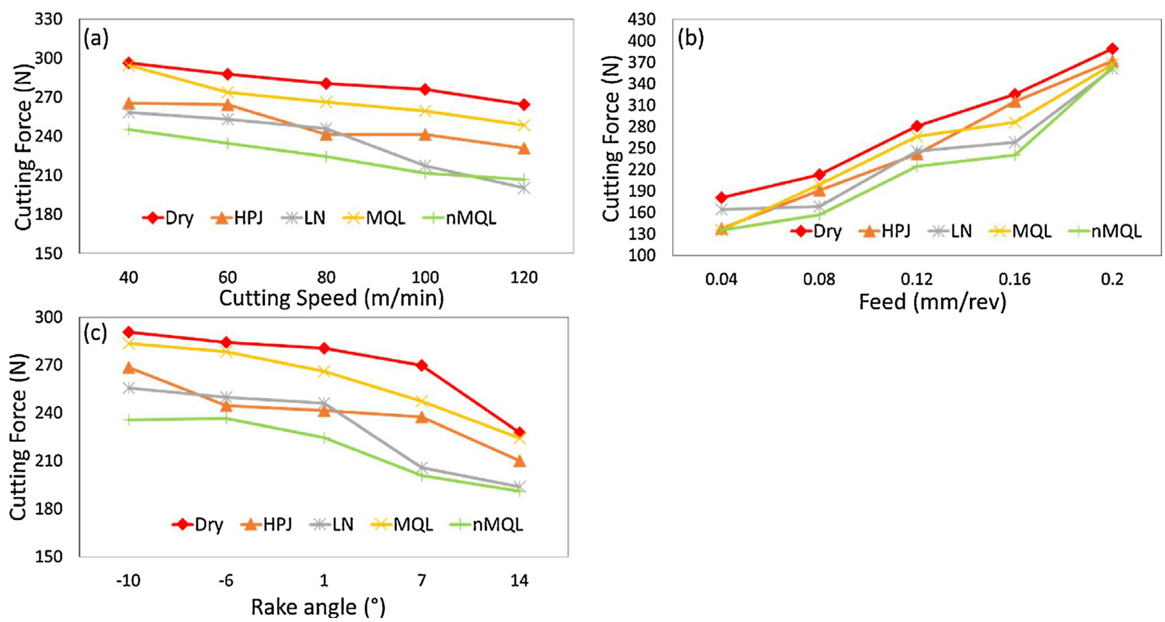

Fig. 2. Variation of cutting forces with (a) Cutting speed (b) Feed (c) Rake angle (Speed 80 m/min, Feed 0.12 mm/rev, Rake angle 1°).

to machine the Inconel 718 [5]. Hence there exists a strong motivation for improving the machinability of these alloys so that the associated cost may be minimized.

In turning process, the heat generated is influenced by friction due to rubbing between tool-chip and tool- workpiece (when the tool is worn) and in the primary cutting zone, heat is generated by deformation. The generated heat strongly affects the life of the tool and the surface quality of the workpiece. The high heat generated during the machining of Inconel 718 is attributed mainly to its high yield stress and poor thermal property. Usually in machining, the maximum amount of heat is carried away by the chips, and the heat generation mostly depends on the cutting velocity, work material, and hardness of the tool. Beyond a certain temperature, the cutting tool may start losing its hardness. Consequently, an increase in temperature may reduce the life of the tool significantly. As a result it is necessary to maintain a lower temperature in the machining zone.

The application of coolant and lubricants in the machining process can reduce the cutting zone temperature. In order to achieve proper cooling and lubrication in the machining zone, several cooling techniques have been adopted. The coolants and lubricants reduce the friction between chip-tool interfaces and also carry away the heat generated from the machining zone. Cutting fluids used in manufacturing industry are water based soluble oils, neat oils, mineral oils etc. However, the fluids create environmental hazards and degrades occupation safety standards. The cutting fluids often have a detrimental impact on the operator's health and may sometimes have an adverse impact on production rate. To overcome these harmful effects, different sustainable machining environments such as high-pressure jet machining (HPJ), cryogenic machining, minimum quantity lubrication machining (MQL), and nano fluid based minimum quantity lubrication machining (nMQL) have been proposed by researchers [6,7] to improve the machinability of Ni-based alloys.

HPJ cooling can be used effectively to break the chips and thereby minimize the contact friction. It can also be used to cool the chip-tool and work-tool interfaces. It can form a hydraulic layer between the chip-tool contacts by penetrating into the interface. When HPJ is applied to the rake face, it changes the chip flow direction, reduces tool-chip contact length and further minimizes the total frictional force [8]. Ojmertz and Oskarson [9] were probably the first researchers who used HPJ while machining Inconel 718.

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