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Tribological Behavior of Inconel 718 and Carbide Tools under nMQL Environment

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Abstract

The aim of this paper is to understand the frictional behavior of nanofluid (NF) at the chip-tool interface. An indigenous tribometer has been used to conduct the experiments. A wide range of flow rate, sliding speed and NF concentrations have been chosen for this study. The sliding speed has been selected based on the tool work combination. The result shows that the coefficient of friction (COF) at chip-tool interface decreases with the increase in sliding speed. However, the friction coefficient gets decreased for flow rates upto 150 ml/hr, and after that, no significant changes have been observed.

Keywords: COF, nMQL, machining, tribometer, ball bearing effect

1. INTRODUCTION

A certain class of alloys does not lose their mechanical properties even in severe thermo-mechanical loading conditions. These types of alloys are called superalloys. In general superalloys are nickel, nickel-iron and nickel-cobalt based alloys generally used at a temperature more than 550°C [1]. These superalloys also have high rupture strength, creep strength, corrosion, cyclic fatigue resistance and oxidation resistance. Due to these unique properties, superalloys have been widely used in the manufacturing of the components of the aeronautical engines, gas turbines, in nuclear and petrochemical applications. They have excellent fracture toughness, and ductility properties at cryogenic temperature and hence, these superalloys have been used in rocket motor casing, cryogenic tank and superconducting structural components [1].

Inconel 718 is one of them which is introduced in industrial application in 1965, and its application increases extensively year by year. This alloy is a precipitation strengthened nickel-based superalloy. It has a polycrystalline structure, which contains both coherent γ' and γ'' precipitates. The γ' precipitates consist of Ni_3Al, and the γ'' is usually made of Ni_3Nb. In this alloy, the primary strengthening phase is γ'' because of its body centered tetragonal (BCT) ordered structure. The coherency of the γ'' and the matrix results in the excellent resistance to strength properties of the alloy even at the elevated temperatures [2].

However, Turning of Inconel 718 is not easy due to the continuous chip formation, poor thermal property, high strength and the presence of carbides in its microstructure. The continuous chip produced during turning gets entangled with the tool holder. This entangling chip then rubbed the machined surface and increased the surface roughness. Chip fragments also get adhered onto the machined surface, and this minimizes the service life of the product. The high chemical affinity of this material causes built up edge (BUE) formation during turning process. Further, this BUE maximises power required and minimizes the tool life. Strain hardening effect of this material maximizes the nose reduction. These detrimental effects lead to an increase in the manufacturing cost. High heat generated during turning of Inconel 718 also detrimentally affect the surface quality of the product. Several surface defects are observed while machining of this material. These are high tensile residual stresses, surface roughness, surface tearing, microhardness, and micro cracks, etc. [3-6]. However, these surface defects mostly minimize the fatigue life of the machined product [7].

For machinability rating (MR), SAE 1020 grade steel (Free cutting steel) is considered as a reference material 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 to machine the Inconel 718 [8].

To minimize the machining cost various lubri-coolant techniques have been used. [9, 10]. The coolants and lubricants reduce the friction between chip-tool interfaces and also carry away the heat from the machining zone. Generally cutting fluids used in the industry are water based soluble oils, neat oils, etc. These fluids, however, create environmental hazards and lower occupational safety standards. The cutting fluids often have a detrimental impact on the operator's health and sometimes may also have an adverse impact on production rate. Application of conventional cutting fluids create various problems such as (a) pollution due to the chemical disintegration of cutting fluid at high temperature (b) contamination of cutting fluid and soil during disposal and (d) health issues for the operator [11-13]. International Agency for Research on Cancer reported that mineral oil used in machining could cause skin cancer [14]. Around 1.2 million workers all over the world are suffering from the respiratory problems due to inhalation of cutting fluids as reported by National Institute of Occupational Safety and Health [13]. Other health issues such as chest pain, respiratory irritation, asthma, chronic bronchitis, etc. are caused due to the inhalation of conventional cutting fluid aerosol. Conventional cutting fluid application cost also detrimentally impact the market price of Inconel 718 components. 7-17% of total manufacturing cost is used for cooling and lubrication. The cutting fluid storage, application and recycling cost is around four times of the cutting inserts used for turning of Ni-based superalloy [15, 16]. To overcome these detrimental effects, different sustainable machining environments have been adopted to improve the machinability of Ni-based alloys which are: High-pressure jet machining (HPJ), Cryogenic machining, Minimum quantity lubrication machining (MQL), Nano minimum quantity lubrication machining (nMQL).

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Nano minimum quantity lubrication machining is the method of application of the minute amount of nanofluids (NF) to the machining zone. This method of application is similar to MQL technique. The NF is prepared by mixing the nano particles (NPs, size≤100 nm) with a base fluid to enhance the thermal and tribological properties of the base fluid [17]. NFs are the colloidal solution of nanosize metallic or non-metallic particles and the base fluid such as oil, water, glycol, etc. Most commonly used NPs are nitrides (Titanium nitride powder), oxides (aluminum oxide, copper oxide), carbides (silicon carbide nanopowder) and nanotubes (carbon nanotubes). Compared to metal working fluids, NFs have several benefits [18], such as improved tribological properties, improved thermal conductivity, and wettability. The use of NFs in turning was probably introduced by Vamsi Krishna et al. [19]. They used mixed nano boric acid of different concentrations with the coconut oil and SAE-40. They used these fluids for turning of AISI 1040 steel. Ali et al. [20] studied the effect of water-Al_2O_3 based NF with and without a surface active agent (Sodium Dodyle Sulfonate) in MQL turning of Ti-6Al-4V. They reported that the nano lubricant with surface active agent improved the machinability in terms of both surface finish and tool wear. Vassu and Reddy [21] experimentally investigated the effect of Al_2O_3 NFs when machining Inconel 600. They reported that addition of NPs in conventional cutting fluid increases the thermal and tribological properties of the fluid.

Application of NFs during machining minimizes the machining force and tool wear and also minimizes the negative environmental impact. Frictional force is the important parameter, which is significantly influence the machinability. However, the most practical approach for identification COF on the rake face is Pin on disc test. The main drawback in pin disc is neither the effect of cutting edge ploughing effect and nor the rubbing of flank surface is considered. Hence, in this work a indigenous tribometer is used to identify the COF at chip tool interface under nMQL environment.

2. MATERIALS AND METHODS

The details of the tribometer is in this study is given in Author's previous work [22]. **Figure 1** shows the tribometer used for friction test under nMQL environment.

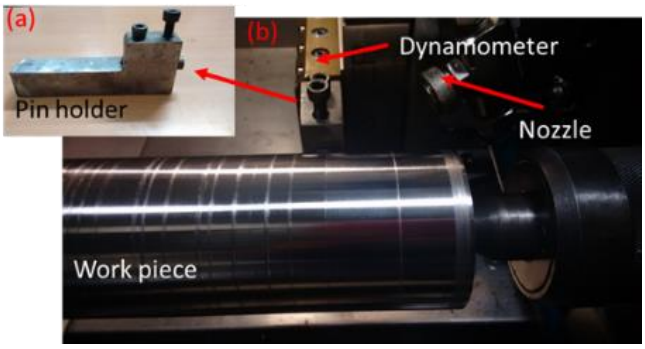

Figure 1. Experimental setup for tribotest

A cylindrical bar of Inconel 718 having consider as chip under surface and carbide pin face is considered as tool surface. In order to minimize the affect surface roughness on friction test the work piece surface is performed finishing operation to achieve the surface roughness below 0.2 µm. The geometry of carbide pin is shown in **Figure 2.**

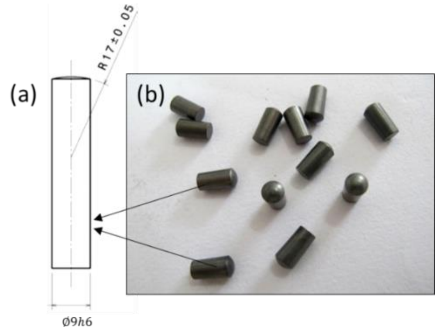

Figure 2. Carbide pin (WC-6Co) used for tribotest

The required amount of pressure between chip and tool was achieved by applying of the normal pressure on the pin. The benefits of this setup is the pin is always rubbed over the fresh surface. The atomized droplets of NFs in nMQL mode applied to the pin and cylindrical bar contact throw the nozzle as shown Figure 1.

Alumina (Al_2O_3) nano fluids are prepared by two step method. NPs having average diameter 40 nm is used to prepare the NFs. The NPs are dispersed in DI water (base fluid) and simultaneously mixed with the help of a mechanical stirrer. Further NFs are mixed with a probe sonicator for 1hr. **Table 1** represents the factors and their levels used for the friction test. Wide range of sliding speed, flow rate and NPs concentration have been chosen for experiments. Effect of each variable on friction coefficient is evaluated taking other parameters constant.

Table 1. Factors and their levels

Parameter	Levels				
	-2	-1	0	1	2
Sliding speed (m/min)	20	40	60	80	100
Flow rate (ml/hr)	50	100	150	200	250
NPs concentration (Vol%)	0	0.05	0.1	0.15	0.2

3. RESULTS AND DISCUSSIONS

3.1 Effect of sliding speed on COF

Figure 3 represents the evolution of **COF** with sliding speed. It is shown that the COF decreases significantly from 0.651 to 0.412 when sliding speed increases from 20 m/min to 100 m/min. This could be due to with increasing in machining speed surface speed of work piece increases. The similar result reported by previous work [23].

3.2 Effect of flow rate on COF

Figure 4 represents the effect of flow rate on COF. The COF obtained 0.648, 0.516, 0.492, 0.445 and 0.443 when the flow rate is 50 ml/hr, 100 ml/hr, 150 ml/hr, 200ml/hr and 250 ml/hr respectively. The COF is decreases when the flow rate increases from 50 to 150 ml/hr. After that the COF has not changed significantly. The possible reason could be with increasing in flow rate number droplets increases and which further maximize lubrication effect. However, when the flow rate is increases above 150 ml/hr the size of the droplets increases.

Maruda et al.[24] reported that with increasing in droplet size intensity of tribo film formation decreases and this could be possible reason behind of it.

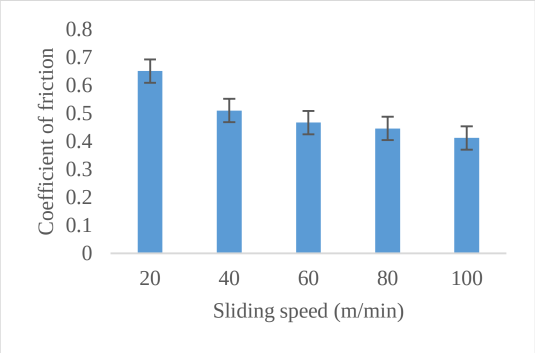

Figure 3. Variation of coefficient of friction with sliding speed (Flow rate: 150 ml/hr, Nano particle concentration: 0.1 Vol%)

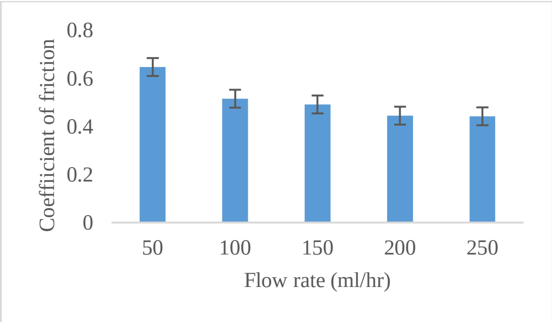

Figure 4. Variation of coefficient of friction with flow rate (Sliding speed: 60 m/min, Nano particle concentration: 0.1 Vol%)

3.3 Effect of NPs concentration on COF

Figure 5 illustrates the effect of NPs concentration on COF. The COF obtained 0.612, 0.506, 0.462, 0.452 and 0.447 when applied 0, 0.05, 0.1, 0.15 and 0.2 vol% concentration NF. The NPs present in the cutting fluid increases the tribological property. It converts sliding motion to roiling motion. The same mechanism also reported in literature [25, 26]. However, above 0.1 vol% the COF does not change significantly. The possible reason could be with increasing in NPs concentration agglomeration of NPs in base fluid increases and results in sizes of NPs is increases. This increases in size of NPs minimizes the surface area and further reducess COF.

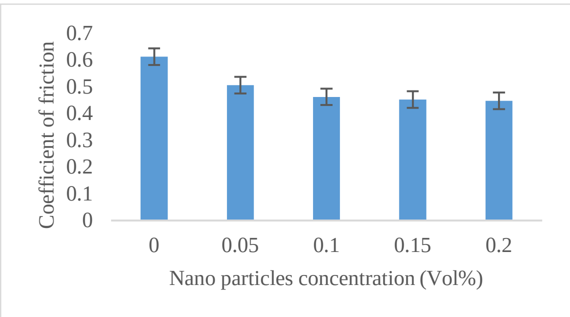

Figure 5. Variation of coefficient of friction with nano particles concentration (Sliding speed:60 m/min, Flow rate: 150 ml/hr)

4. CONCLUSIONS

A tribo test have been conducted between Inconel 718 work surface and carbide pin under nMQL environment. Based on the experimental results following conclusions can be drawn.

- With increase in sliding speed the COF is decreases.
- The COF is decreases up to 150 ml/hr after that there is no significant variation in COF.
- The COF is decreases when NPs concentration is increases up to 0.1 Vol% and after that no significant change is observed.

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