Performance Investigation of minimum quantity lubrication (MQL) Parameters using Nano fluid: A comprehensive review

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Abstract - *In metal cutting operations, the cutting fluid plays important role in cooling the cutting tool, work piece surface and removing chips from the heat-affected zone. However, improper use and disposal of cutting fluids can pose risks to human health and the environment. This paper reviews significant research on the application of MQL (Minimum Quantity Lubrication) using Nano fluid based cutting fluids in various machining processes like drilling, turning, milling, and grinding. In turning operations, parameters such as cutting speed, depth of cut, feed rate and tool nose radius influence surface finish. High-speed turning of steel generates elevated cutting zone temperatures, leading to dimensional deviations, tool failure and micro cracks. Proper selection of the MQL system and cutting parameters allows cost-effective MQL machining with minimal coolant for improved lubricity, tool life, control cutting temperature and surface finish. This study's finds highlights the potential of MQL with Nano fluid as a substitute for flood lubrication, particularly in getting high surface finish*.

Key Words: Machining Process, Nano cutting fluids, Minimum quantity of lubrication, Machining parameters & Cutting Force.

1. INTRODUCTION

The main challenge associated with metal cutting processes is effectively managing temperatures at the tool-work piece interface. High friction at the tool-chip interface and tool-work piece, resulting from continuous mechanical rubbing leads to heightened thermal loads in the cutting zone. Elevated temperatures in this shear zone contribute to the formation of micro cracks on the tool, ultimately reducing cutting tool lifespan. Traditional cutting fluids, employed to absorb heat and act as coolant and lubricants, exhibit lower thermal conductivities. [1]

Commonly used water and mineral oil-based cutting fluids with lower thermal conductivities result in inadequate heat transfer rates, leading to increased tool wear and undesired surface roughness. Furthermore, these conventional cutting fluids pose health risks to machining operators and environmental concerns upon disposal. Consequently, there is a growing demand for cutting fluids with improved thermal conductivity and Minimum Quantity Lubrication (MQL) [2]. In any manufacturing industry, machining is prevalent, inevitably generating heat during the process. Heat generation can damage the surface morphology of the work piece and rate of tool wear. Effectively reducing and dissipating the generated heat is essential to minimize thermally induced loads on the work piece-tool interface. Conventional cutting fluids pose health risks, causing skin infections and environmental issues. Nano-fluid MQL is gaining attention for its potential to reduce lubricant quantities while effectively dissipating heat.

1.1 NANO FLUIDS: PROPERTIES AND PREPARATION:

Nano fluids is a uniform colloidal suspensions composed of nanoparticles, including metals (Al, Cu, Ag, Fe, Zn, Au), non-metals (graphite, GnP, CNT, carbon onion, ND, MWCNT), metallic/non-metallic oxides (Al_2O_3, CuO, SiO_2, Fe_3O_4, Fe_2O_3, TiO_2, ZnO, ZrO_2, GO), ceramic (SiC), and others (hBn, MoS_2), within a base fluid. When compared to conventional bulk materials, nanoparticles exhibit distinctive characteristics, such as:

- Increases thermal conductivity and superior heat transfer capability.
- Motion of nanoparticles induced by thermal effects.
- Elevated viscosity and surface tension.
- Increased specific surface area.
- Modifiable characteristics such as: wettability, anti-friction capability, anti-wear mechanisms, thermal conductivity, dynamic viscosity can be adjusted by changing nanoparticle size, shape, concentration in the base fluid, stability time, sonication duration, choice of surfactants, formation techniques and similar factors.

The synthesis and preparation of Nano fluids can be accomplished through two distinct methods: single/one-step preparation and two-step preparation. The choice between these methods depends on the requirements of the application.

The one-step preparation method is typically used when the primary concern is achieving high dispersion of nanoparticles with minimal sedimentation. On the other hand, the two-step preparation approach is often chosen due to its reduced complexity and greater flexibility. This method is generally more cost-effective compared to the single-step method.

In the two-step method, the first step involves mixing nanoparticles into powder form, followed by their dispersion into base fluids. However, a drawback of this approach is the lower stability of Nano fluids due to the rapid agglomeration tendency of nanoparticles. [3]To address this limitation, researchers have explored various strategies, including pH control, the addition of surfactants/dispersants, surface modification, incorporation of ionic liquids and ultrasonic agitation. These efforts aim to enhance the stability of Nano fluids and mitigate the agglomeration challenges associated with the two-step preparation method. [4]

To achieve a reduction in cutting force, cutting temperature, surface roughness and tool wear during machining, it is essential to consider specific factors. These include the selection of nanoparticle-infused fluids, the dimensions and configurations of the nanoparticles and concentration of nanoparticles. Adjusting these parameters can contribute to outcomes in machining such as improved tool performance. [5]

1.2 EFFECT OF NANO-FLUID ON MACHINING PARAMETERS:

Various researchers have investigated the effect of both conventional and Nano fluid on machining parameters, including cutting force, work piece morphology, machining temperature and tool wear. This study highlights key findings derived from their investigations.

Mao et al. [7] concluded that in the context of Minimum Quantity Lubrication (MQL) grinding, the Nano fluid led to superior grinding performance as evidenced by a reduction in surface roughness and grinding force compared to MQL grinding with a base fluid. The researchers delved into the impact of Nano fluid in the MQL grinding process through wear and friction experiments. The results indicated that the incorporation of Nano particles into the base fluid resulted in decreased friction and enhanced anti-wear properties. It was observed that the inclusion of Al_2O_3 Nano particles in deionized water led to a lower friction coefficient compared to pure deionized water.

Mohd et al. [8] found that introducing SiO_2 Nano lubricant in the cutting process resulted in reduced thermal deformation and friction, leading to a higher surface quality. The analysis of AL6061-T6 after machining with SiO_2 Nano lubricant at varying concentrations revealed that a higher Nano lubricant concentration, specifically at 0.2%, increased the growth of thin protective film on machined surfaces. This growth was attributed to the breaking process facilitated by billions of Nano particles between the tool-chip interfaces. The formation of this thin film was concluded to enhance machining performance

R.S. Revuru et al. [9] Coconut oil is base fluid, with two distinct solid lubricants boric acid and molybdenum disulphide dispersed. The investigation focused on various machining parameters, including cutting forces, cutting temperatures and surface roughness, while employing the developed fluid formulations in MQL. Nano fluids demonstrated superior performance under the specified cutting conditions. To further understand and predict forces and cutting temperatures, a finite element-based model was created.

M. S. Najiha et al. [10] underscored the importance and imperative of achieving process sustainability in manufacturing. The paper elucidates sustainable manufacturing techniques, encompassing dry machining, minimum quantity lubrication (MQL) with solid lubricant, cryogenic coolant and Nano fluid MQL. It suggests that a significant portion (15–20%) of the overall machining cost is attributed to cooling and lubricating fluids. The cumulative cost to procuring, maintaining and disposing of these fluids may constitute around 17% per component in the automotive industry.

TABLE 1: Effect of Nano fluid on different machining parameters

MILLING							
Author of the Paper	**Work piece Material**	**Tool Material**	**Nano Particle (size nm)/ Concentration**	**Base Fluid**	**Input Parameters**	**O/P Parameters**	**Effect of Nano machining**
H.B. Kulkarni et.al. [15] [2019]	AI7075-T6	Uncoated carbide	Cu coated Al2O3	Vulcan Strub Futura 10-9402 NC Coolant oil	Spindle speed=(3000, 4000, 5000, 6000, 7000)rpm , feed rate=(95, 105, 110, 115, 125) mm/min depth of cut= (0.5, 1.0, 1.3, 1.6, 2.0)mm	Surface finish (Ra), temperature values (T)	Reduced roughness and work piece temperature
B.Rahmati et. al [16] [2014]	AL6061- T6 alloy	Tungsten carbide	MoS2 20-60nm 0.1,0.2,0.5, 1vol%	Ecocut HSG 905S oil	Cutting speed= 8000mm/min feed =2100mm/min and depth of cut=10mm	Surface roughness and cutting force	Minimum cutting force arrive by adjusting the nozzle angle at 60 degrees
I.P. Okokpujie et al. [17] [2019]	Mild steel	HSS	TiO2 , SiO2 , Al2O3 15, 14, 13nm	water	Depth of cut - d (mm) 2 2 Spindle speed - N (rev/min) 200 - Feed rate – f (mm/tooth) 1	Temperature	AL2O3 shows good result than the other Nano fluid.
Binayak S. et. al [18] [2020]	Inconel 690	Coated carbide CNGG 120408-SGF-H13A	Silica 5nm 0.5,1,1.5 %	Palm oil	cutting speed =60-100 m/min, feed rate = 0.05-0.25 mm/tooth, and depth of cut = 0.2-1.0 mm	Tool life, surface roughness, resultant cutting force, and cutting temperature	A palm oil medium with a silica deposition of 1% exhibits superior performance across all machining responses.
Fatih G. [19] [2020]	Hastelloy C276 alloy	Hard abrasive carbides	AL2O3 0.5, 1.0 and 1.5 vol%	Vegetable oil	Feed rate = 0.12mm/rev and cutting speed =90m/min	Surface roughness, tool wear and tool life	1 vol% Al2O3 concentration improve up to 23% and 10% in tool life, compared to 0.5 vol% and1.5 vol%

TURNING							
Author of the Paper	**Work piece Material**	**Tool Material**	**Nano Particle (size nm)/ Concentration**	**Base Fluid**	**Input Parameters**	**O/P Parameters**	**Effect of Nano machining**
Oleksandr G. et al. [20] [2018]	Alloy 718	Micro-grain coated CC	Graphite Nanoplatelets (GnP) 30nm, 0.2%vol	Vegetable oil - based lubricant	Feed rates = 0.08, 0.125, 0.16 mm/rev cutting speeds = 40, 50, 60 m/min	Surface Roughness, cutting force and tool wear	Increases tool life, surface finish and process stability
P. Kumar et al. [21] [2021]	Duplex stainless steel (DSS-2205)	-	Al2O3, CuO 30 –50 nm (0.3, 0.5 and 0.7 vol. %)	DI water	Speed = 64.74 m/min, feed = 0.051 mm/rev and Depth of cut =0.4 mm	Temperatureand surface roughness	Better result of surface roughness and cutting force by Al O2 3 nano fluid (0.7%) is obtained.
A. Yiicel et al. [22] [2021]	AA 2024 T3 aluminum alloy	Uncoated cemented carbide ISO code: VCGT 160404 FL	MoS2 80nm (0.6% vol. conc.	Mineral oil	Cutting speed = 300, 400 ,500 m/min Feed rate = 0.1, 0.2 , 0.3 mm/rev Depth of cut = 1 mm	Surface topography, temperature, and surface roughness	Upgrade in surface roughness and surface topography is obtained. Built-up edge formation is also significantly low.
P.B. Patole et.al. [23] [2017]	AISI 4340		Multi Walled Carbon Nano Tube MWCNT 15 nm 0.2% vol. conc.	Ethylene glycol	Cutting speed = 75 m/min, Feed = 0.04 mm/rev, Depth of cut =0.5 mm and Tool nose radius = 0.8 mm	Surface Roughness, cutting force	The machining efficiency in MQL turning of AISI 4340 under MQL mode can be enhanced.

DRILLING							
Author of the Paper	**Work piece Material**	**Tool Material**	**Nano Particle (size nm)/ Concentration**	**Base Fluid**	**Input Parameters**	**O/P Parameters**	**Effect of nano machining**
J.S. Nam et al. [24] [2015]	Aluminium	Uncoated carbide twist drill (DIXI1138, DIXI),	Diamond 30 nm (concentration: 2, 4,0 % vol.	Paraffin and vegetable oils	Drill diameter =0.50,0.3, 0.1mm Feed rate=15,12.5, 10.0 mm/min Spindle speed =60000, 5000,30000 rpm	Torque , Thrust force MRR	Minimise drilling torques and thrust forces and maximized material removal rate (MRR).
D.G. Subhedar et al. [25] [2021]	Stainless Steel 304	HSS twist drill	Al2O3 0.3,0.8 and 1%	Mineral oil-based	Speed =1000 ,1500 rpm feed rate = 0.050 mm/rev.	Tool life and surface roughness	Nano coolants increases the tool life and reduces the surface roughness. Tool life is highest for Nano cutting fluid of 1% volume fraction and achieve the lowest surface roughness 2.01 µm at 1000 rpm.
M. Mosleh et.al. [26] [2019]	Titanium 6Al4V (Ti)	Tungsten carbide	MoS2 , hexagonal boron nitride 70-100 nm, 3-5 nm 2%	Boeblube 70104 oil	Cutting speed = 1.0 m/s	Tool wear and torque	MoS2 reduce the build-up of the Ti transfer film on WC tools in orbital drilling.
A. Pal et al [27] [2020]	AISI 321 stainless steel	Two-flute M35 high speed steel (HSS)	Graphene 0.5 wt%, 1.0 wt% and 1.5 wt%	Vegetable oil	Max speed = 2500 rpm	Thrust force torque, surface roughness, coefficient of friction (COF) and drill wear mechanism	Graphene nanofluid have the potential to enhance lubrication efficiency, elevate the stability of the lubrication film.

3. CONCLUSIONS

Different machining processes such as drilling, milling, turning and grinding, examined concerning the impact of Nano fluid-based coolants on surface roughness, cutting force, tool temperature and tool wear. The Nano fluid (MQL) techniques improve surface finish and increased tool life compared to traditional machining.

Key findings from the literature review:

• Limited research has been conducted on drilling and milling processes, the need for

Increased focus in these areas.

• MQL with Nano fluid is eco-friendly machining process.

• There is potential for machining and operating parameters using suitable

Nano lubricants.

• Further investigations particularly exploring the application of hybrid Nano fluids in

the machining of different metals and metal alloys.

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