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Investigation of Nanofluid as a Coolant for Different Machining Process – A Review

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ABSTRACT
In last, few decades many researchers focus their study the potential of nanofluid for different applications. as a many manufacturing process lubricant plays an important role.Nanofluid is very efficient heat transfer fluid because of their enhanced thermal and tribological properties. This motivates to investigate the potential of nanofluid as a lubricant in many heat transfer applications like milling, grinding, drilling etc. to enhance the quality of machining processes. This paper presents a summary of different nanofluid used as a lubricant in various machining process by various researchers and their findings. This review article also explicates the effect of size and volume fraction of nanoparticle on machining parameters, environmental effects, tool lifeand surface finish. In this Paper focus is given on use of nanolubricant in the minimum quantity lubrication (MQL) technique used for different machining processes. The MQL technique reduces the cutting parameters as compare to dry and wet machining.

KEYWORDS
Nanofluids, cutting fluids, cooling technique, MQL, machining, parameters.

INTRODUCTION

Nowadays, machining processes are plays vital role in manufacturing industry. In manufacturing industry at the time of various cutting operation, cutting fluid plays an important role to: a) lubricate the tool and work piece interference. b) remove the chips from cutting zone. C) cools the workpiece and cutting tool. To enhance the quality in machining, efficient cutting fluid is required to remove the heat generation while cutting.The cutting fluid can be classified as shown in figure 1[1].In that ionic liquid is found great potential as eco-friendly functional lubricant in micro milling process with improved surface finish as compare to conventional lubricant[2]. As some of the conventional fluids are badly affected the environment and human health during input as well as discharge, uses of these fluids should be avoided [3].The major cooling techniques are shown in figure 2[4]. Among all Morden techniques MQL have better performance using conventional fluids because of its eco-friendly qualities [5]. Specially in the micro milling machining, MQL technique improves the machining parameter and reduce hazards effects[6].

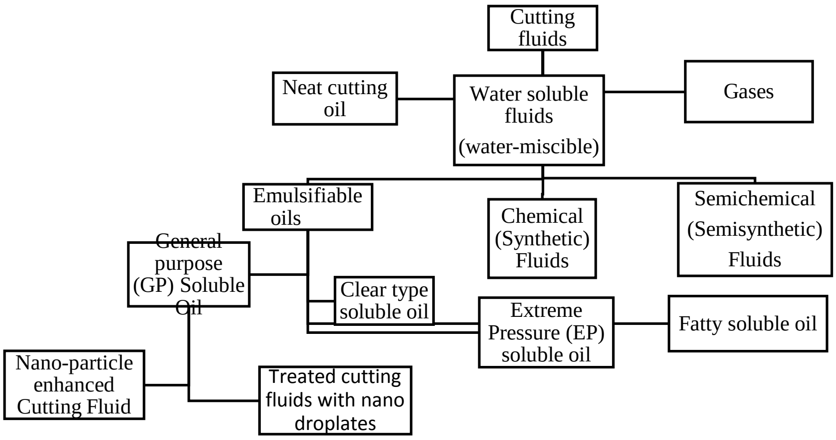

Fig 1. Classification of cutting fluids

As the conventional coolant are less efficient heat transfer fluid, researcher starts their investigation to study the performance of nano fluid as a coolant for different machining process. Nanofluids is a fluid containing nanometre-sizes particles suspended in carrier fluid. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Dr. Choi has tossed the concept of nanofluid[7]. By adding the nanoparticles in low efficient heat transfer fluid can attain the stable and highly efficient heat transfer fluid[8].TheNanofluids have good thermal conductivity over conventional fluid, mixture of nanoparticle and conventional cutting fluid called nanolubricant. Nanolubricant made to improve stability, thermal conductivity, rheological properties, tribological properties and no negative effect on pressure drop to get efficient performance for any machining processes[9] and[10].The main aim of present study on application and effects of nanolubricants in different machining operations like drilling, milling, turning, and grinding.

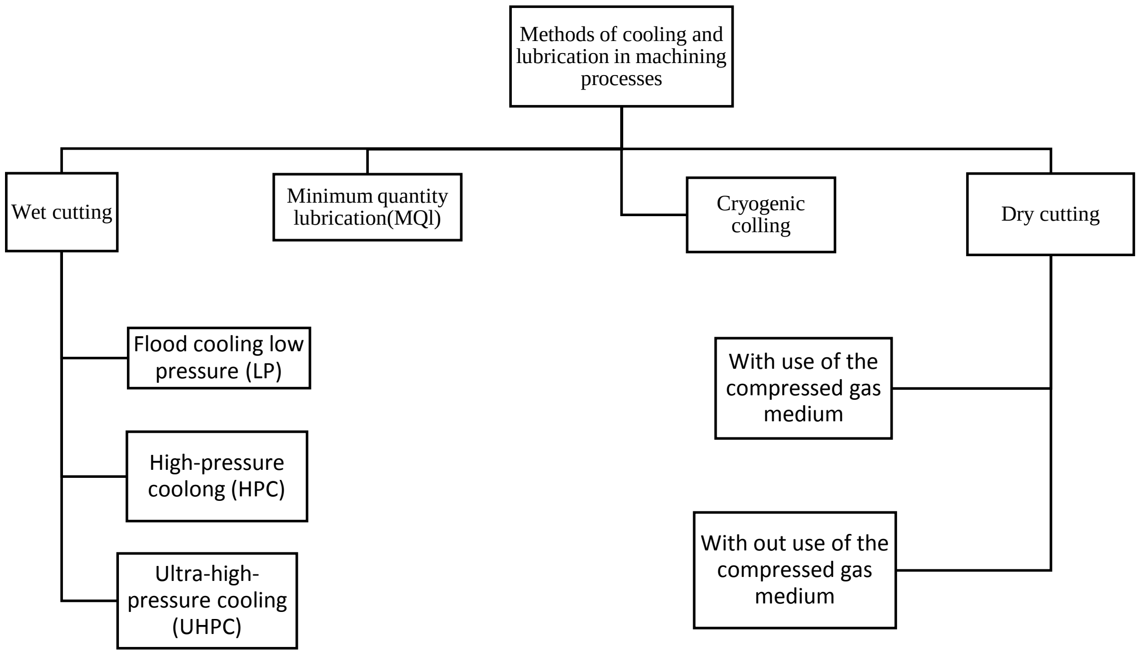

Fig 2. Cooling techniques

MINIMUM QUALITY TECHNIQUE

MQL is very effective technique for any machining processes.In this technique, a very small amount of coolant is spread with the help of automizer under pressure in cutting zone. The pressurised air is used in the automizer to increase the pressure of the coolant. Atomized coolant is impinged in the cutting zone by the air in a low-pressure distribution system. Due to the venture effect in the mixing chamber, partial vacuum sucks the cutting fluid from the oil sump where it is maintained at a constant hydraulic load.

Accordingly, mode of cutting fluid delivery to cutting zone, MQL technique divided in two categories as shown in Figure 3(a) internal feed system and Figure (b) external feed system. It is conclude that internal feed system has more effective than external feed system[11].Researcher also conclude that the MQL technique is more efficient than dry and wet technique. Figure 4 shows the performance of different coated toolslike: a) coating A (TiCN/Al2O3/TiN) b) coating B (TiN/AlN) c) coating C (TiAlN) for turning operation. In that it is observed that supply of ester and compressed air based oil by MQL technique gives efficient performance than wet and dry technique, it also increase tool life and surface finish[12].

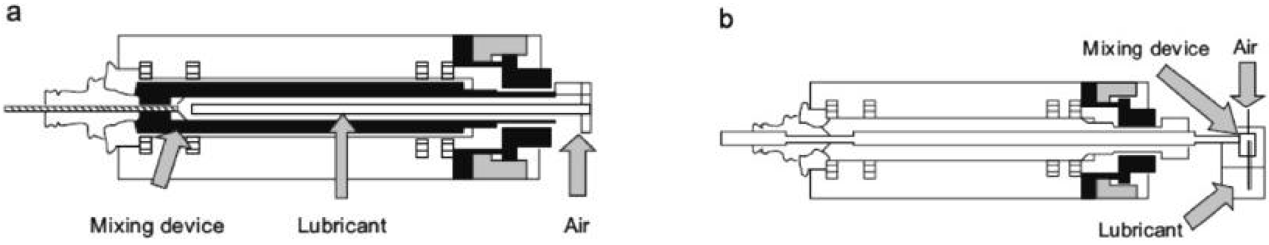

Fig 3. (a)internal feed system (b)external feed system

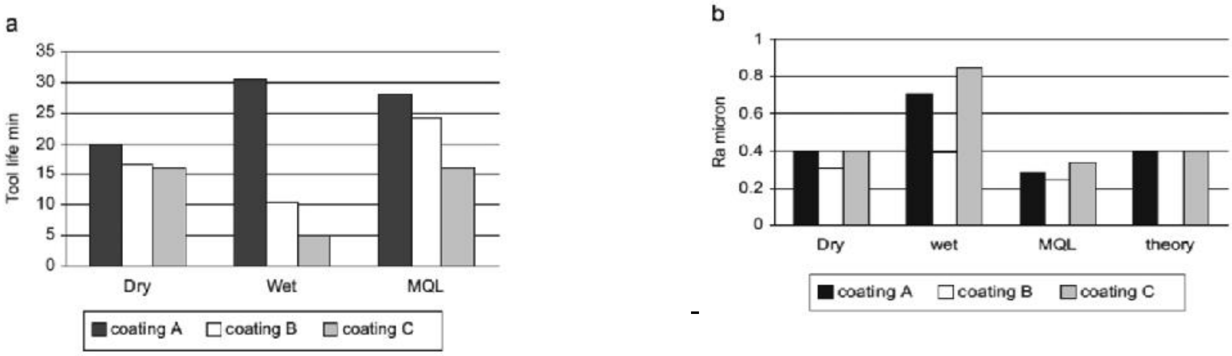

Fig 4. Tool life and Surface finish in Dry, Wet and MQL machining for different coated tool

APPLICATION OF NANOFLUID IN MACHINING PROCESSES

It has been proved that many researchers that addition of nanoparticle in base fluid enhances the cooling capability of nanolubricants. This section summarizes the investigations done by various research groups to study the application of nanofluid in different machining processes.

DRILLING

In this proceses material is remove by giving circualr motion to spiral fluted cutting tool. A number of experiments conducted on micro-drilling process with MLQ technique using dimond nanopartical having diameter of 30nm mixing with the base fluid of paraffine and vegitable oil. For micro drilling process, uncoated carbide drill havin diameter of 200µm is used to makin holes in aluminium workpiece. Supply of lubricant under condition of comoressed air lubrication and Nanopartical concentration in base fluid are 1vol% and 2vol%. Quality of drills investigate by SEM(Scanning electron microscope). From the results it clealy shows that nanolubricant in MQL, increses the number of drill holes and reduction in drill torque and thrust force. Figure 5. Shows the drill torque and thrust force in different concentrations of nanolubricant. It shows 1vol% concentration gives better result than 2vol% concentration and also reduces the failure of drill while using MQL techinque [13].

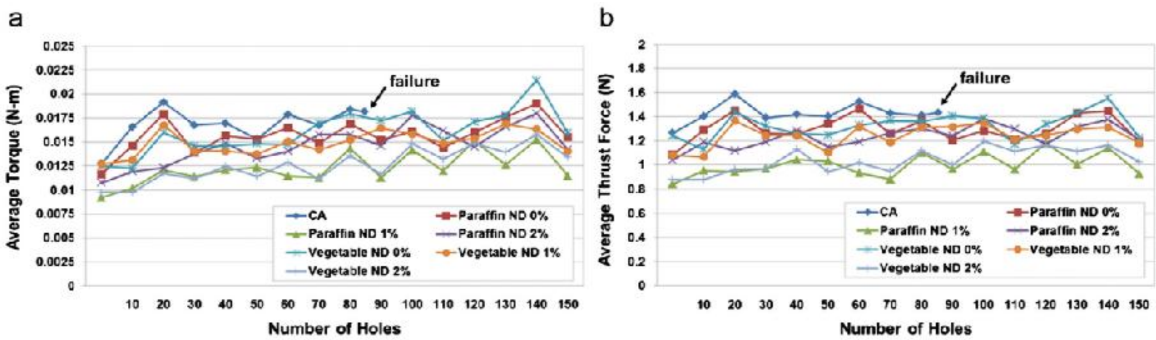

Fig 5. (a) drill torque and (b) thrust force during micro-drilling

TURNING

Turning is a fundamental process to produce round shape workpieces in manufacturing industry.This investigation presents on application of small quantity lubricant supply in high speed turning of AISI 4140 steel with TiN coated carbide insert using nanofluidas multiwall carbon nanotube containing concentration of 1vol% and 3vol%in basefluid Ethlene glycol using MQL technique. The 3vol% alimina and 1% MWCNT showed reduction in cutting force and specific enenry. Result shows that MWCNT is more effective than alumina for reducing tensile stress as shown in figure 6, which reduse temerature at cutting z-one and improve tool life [14]. Table 1 shows some important reseachers on turning processes with using different nanolubricant and their effects on maching parameters.

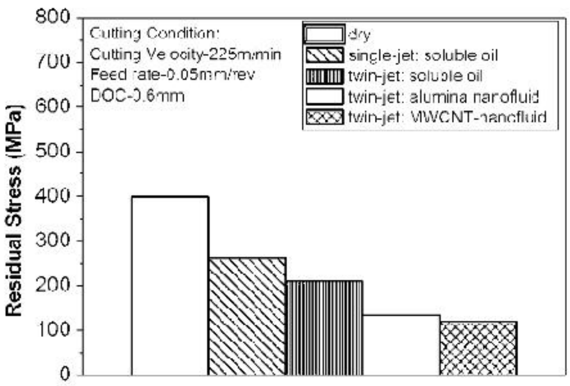

Fig 6. Residual stress on machining surfaces under different cutting environments

Table 1. Review of nanolubricant and their effects on machining parameters during turning process

Author Group/s (year)	Nanoparticle (size nm)/ Concentration	base fluid	Machining parameters (Cutting speed-Feed rate- Depth of cut)	Mode of nanofluid supply	Effects of nanolubricants in machining
M. Sayutiet al.[15] [2014]	SiO_2 5-8nm 0.2,0.5.1.0wt%	Minral oil	120m/min 0.5 mm/rev. 0.5mm	MQL	Nanoparticle generate thin protective layer on machining surface and it reduces coeffecient of friction.
Prasad and Srikant [16] [2013]	Nano graphite 80nm 0.2.0.3.0.5wt%	Water and soluble oil	105m/min 0.14mm/rev. 1.0mm	MQL	Addition some amount of nanoparticle decreses the cutting speed,surface roughness and tool wear and temperature.
Khandekar	Al_2O_3	Survo-	350m/min	-	Improved

et al.[17] [2012]	- 1vol%	cut-'S'	0.1mm/rev 1.0mm		lubricating and heat removal prperties and reduce cuting force, wear and roughness due to better wettability.
Yan et al.[18] [2011]	MoS2 /GF/ Cu/ CuO 1000/ 150/ 200/ /48 nm 10wt%/ 3wt%/ 10wt%/ 10wt%	Grease	1000 RPM 20mm/rev. 0.5mm	Nanolubricant spreed over work piece	Due to higher plasticity,exhibit excellent lubrication. 10% mixter in grease produce reduce surface roughness and tool wear.
Krishna et al.[19] [2010]	Nanoboric acid 50nm 0.25%, 0.5%, 1.0vol%	SAE-40 oil and coconut oil	60/80/100m/min 0.14/0.16/0.2mm/rev 1.0mm	Under atmoshpheric pressure with 10ml/min flow rate	It has great chemical affinity for metal surface, resulting lower friction and increase heat transfer capacity.

GRINDING

For finishing of any component grinding is widely used maching process that gives smooth surface and precise tolerance . In grinding, controlling tool-workpiece interarence temperature is masure problem. An experiment using Al_2O_3 nanopartical mixing emulsifer to reduce heat generation during grinding. Experiment conducted on EN-21 steel grinder and flood lubrication technique. 1vol% of nanoparticle mixing in emulsifer and giving different feed to grinding machin and final result shows the better surface finish with respect to temperature as shown in figure 7 [20]. Table 2 shows some important reseachers on grinding processes with using different nanolubricant and their effects on maching parameters.

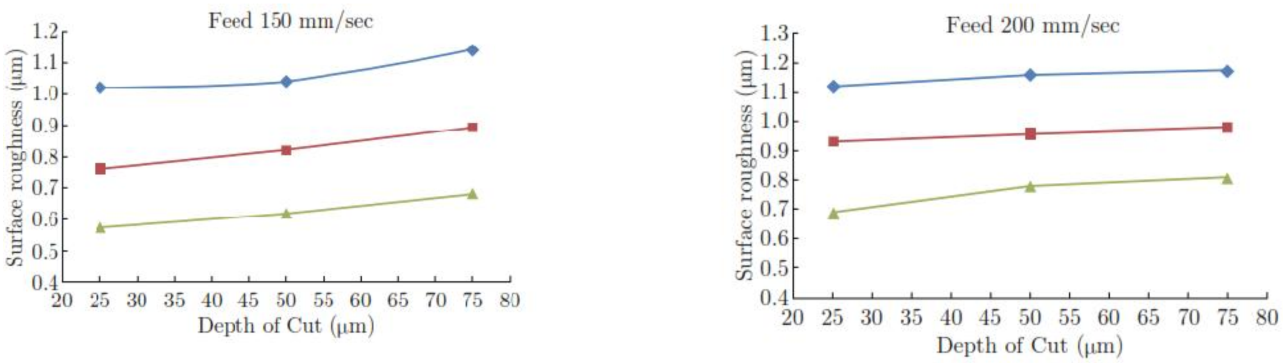

Fig 7. variation of roughness for different cutting environment

Table 2. Review of nanolubricant and their effects on machining parameters during grinding process

Author Group/s (year)	Nanoparticle (size nm)/ Concentration	base fluid	Machining parameters (wheel speed/ Workpiece speed/ Depth of cut)	Mode of nanofluid supply	Effects of nanolubricants in machining
Mao et al. [21] [2014]	Al_2O_3 10nm MoS_2 70nm 1vol%	Deionized water and Canola oil	31.4 m/s 0.05 m/s 10mm	MQL	Reduction in friction and anti -wear properties while using Al_2O_3 than MoS_2.
Mao et al. [22] [2013a]	Al_2O_3 60nm 5vol%	Deionized water	31.4 m/s 0.05 m/s 10mm	MQL	Reduces surface roughness, grinding forces and temperature by adjusting nozzle angle near to contacting area.
Mao et al. [23] [2013b]	Al_2O_3 40nm 1, 3, 5vol%	Deionized water	31.4 m/s 0.05 m/s 10mm	MQL	Reduction in grinding temperature, grinding force & surface roughness.
Prabhu and Vinayagam[24] [2012]	CNT 10-20nm 1vol%	SAE-20W40 oil	2000RPM 1.9 mm/rev 0.2mm	-	Improve surface roughness.
Lee et al. [25] [2012]	ND 30-150nm Al_2O_3 30-150nm 2vol%,4vol%	Paraffin oil	80000RPM 120mm/rev 5mm	MQL	Due to low hardness Al_2O_3 Improve surface roughness than ND.
Kalita et al.	MoS_2	Paraffin	30m/s	MQL	Reduce friction,

[26] [2012a]	<100nm 2,8wt%	oil and soybean oil	0.06m/s 10 and 20mm		energy consumption and grinding ratio while working on cast iron.
Kalita et al. [27] [2012b]	MoS_2 40-70nm 2,8wt%	Paraffin oil	30m/s 0.06m/s 10 and 20mm	MQL	MoS2 reduced force-ratio, specific energy and wheel wear.
Prabhu and Vinayagam [28] [2010]	MWCNT 10-20nm 0.5wt%	SAE-20W40 oil	2000RPM 1.9 mm/rev 0.2mm	MQL	Surface quality improve.
Lee et al. [29] [2010]	ND 30 and 150nm 2,4vol%	Paraffin oil	80000RPM 120mm/rev 5mm	MQL	Size of particle not effected on grinding force. 30nm produced best surface.
Alberts et al. [30] [2009]	xGnPs 5-10nm 0 to 2wt%	IPA, TRIM SC200	25 m/s 750mm/rev 50µm	MQL	1%wt gives better surface for 5nm particle.
Shen et al. [31] [2008]	Al_2O_3 40nm ND 100nm 1,2.5,4,5vol%	Deionized water	30m/s 2400mm/rev 10µm	MQL	4 % Al_2O_3 concentration gives better grinding ratio while surface under flood cooling.

MILLING

In this machining process workpiese are fixed on rotating table and chip removed by rotational and multi teeth tool. Cutting fluides are utilized in miiling operation because of contact of multi teeth. In milling process with $SiO_2$110nm diameter and diamond 92nm diameter particles mixing with base fluid paraffin oil. SiO_2 particle more effectively work than dimond particle. Using different concentration 0.1,0.2,0.5, and 1.0wt%,threre is no change in performance iron work piece. Figure 8 shows coefficent of friction with respect to time for

0.2wt%concentration.[32]**.** Table 3 shows some important reseachers on milling processes with using different nanolubricant and their effects on maching parameters.

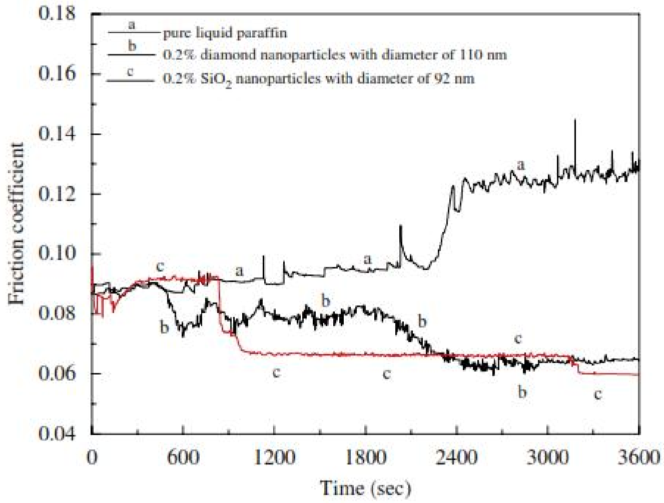

Fig 8. coeffecient of friction during different lubricants with respect to time

Table 3. Review of nanolubricant and their effects on machining parameters during milling process

Author Group/s (year)	Nanoparticle (size nm)/ Concentration	base fluid	Machining parameters (Cutting speed-Feed rate-Depth of cut)	Mode of nanofluid supply	Effects of nanolubricants in machining
Rahmati et al.[33] [2014]	MoS_2 20-60nm 0.1,0.2,0.5, 1vol%	Ecocut HSG 905S oil	8000mm/min 2100mm/min 10mm	MQL	By adjusting nozzle angle at 60˚ minimum cutting force achieved.
Rahmati et al. [34] [2013]	MoS_2 20-60nm 0.1,0.2,0.5, 1vol%	Ecocut HSG 905S oil	5000mm/min 100mm/min. 5mm	MQL	0.5wt% MoS_2 produced best surface quality.
Sayuti et al. [35] [2013]	SiO_2 5-15 0.2 to 1.0vol%	Ecocut SSN 322 oil	75.408m/min 100mm/min 1mm	MQL	Adjusting nozzle angle at 60 gives minimum cutting force for 0.2% concentration.

Sayuti et al. [36] [2013]	SiO_2 5-15 0.2,0.5, 1.0vol%	Ecocut SSN 322 oil	5000mm/min 100mm/min. 5mm	MQL	Generate protective film and increasing concentration helps to reduce surface roughness.
Sarhan et al. [37] [2012]	SiO_2 5-15 0.2wt%	Ecocut SSN 322 oil	5000mm/min 100mm/min. 5mm	MQL	Reduction in power, cutting force and specific energy.
Park et al. [38] [2011]	xGnP - 0.1,1.0vol%	Vegetable oil	3500/4500 RPM 2500 mm/min 1mm	MQL	Noticed lowest coefficient of friction.

CONCLUSION

According to literature review, the nanolubricants exibits better tribological properties as compare to base fluid. Most of the studies showed that tribological properties improve with increasing concentration of nanofluid into base fluid. Also, showed that nanolubricant reduce power consumption,surface roughness,cutting force,temperature, specific energy,tourque in drilling,tool wear,friction and imroves surface quality, tool life and grainding ratio during machining processes.

- Cu nanoparticle generated lowest surface roughness <5 nm among all other anoparticle while mixing with grease.
- Al_2O_3 nanoparticle generates lowest surface roughness 0.1µm while mixing with paraffin oil, especially in case of smaller size.
- ND mixing with paraffin oil give better performance than mixing with vegitable oil for drilling holes.
- MoS_2 nanoparticle generated lowest cutting force while pressur id 4bar and nozzle angle 30˚.
- SiO_2 nanoparticle mixing with ECOCUT SSN 322 oil with high pressure and nozzle angle 60˚ showed minimum cutting force and better surface at nozzle ange 30˚.
- There are less researchers to work on drilling and turning processes. Hence more attention is required to unfold the effect of nanolubricants in these processes.
- In area of several operating parameter and machining parameter should be optimize using suitable nanolubricants.
- Further investigation can also be focussed on the application of MQL with hybrid nanofluids in machining of different metals and alloys.

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