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Study the Effect of various Nanofluids in different Machining Process and Machining characteristics: A Review

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ABSTARCT: When the metallic or non-metallic particles of nanaometered size (<10-9m) are mixed in conventional cutting fluid (like mineral oil, vegetable oil, lubricating oil, etc.) is called nanofluid. During conventional machining dry method used where no coolant/lubricant used hence increased in temperature cause distortion of machine. Therefore, various machining like drilling, milling, grinding, and turning used various minerals/vegetable oils which only act as lubricant and also cause adverse effect on environment and health of workers so small size (macro or micro particles of metal or non-metal) are used into the oils for increasing thermal conductivity but problem of clogging takes place. Various properties of nanofluid like thermal conductivity, good lubricating property and rheological properties attracted attention of various researchers towards it and many tests (machining) are performed with nanofluid. This review paper presents a summary of some important published research works on application of various nanofluids in different metal removal process like drilling, milling, turning and grinding. The review article also describe the various parameters like Nanoparticle's concentration in base fluids, Nanoparticle's shape, size, spray nozzle orientation, distance of spray and lubrication mode. From literature review, it is found that various properties (surface finish, thermal conductivity, etc) are obtained at appropriate concentration only. Furthermore, we study the NP's in basefluid which together reduces the tool wear, thrust force, surface roughness, power consumption, cutting temperature and coefficient of friction and also due to small size particles the clogging problem reduced. The summary and conclusions are also presented on basis of data collected and some area for future research is also identified.

Keywords: Nanofluid, MQL, Surface Roughness, Thermal Conductivity, Tool Wear, Coolant and Lubricant, Drilling, Milling, Turning and Grinding.

Abbreviations: CNT, Carbon Nano-Tube; EG, Ethylene Glycol**;** G-ratio, Grinding ratio; G- force, Grinding force; Hbn, Hexagonal boron nitride; MWCNT, Multi-Walled Carbon Nano-Tube; MQL, Minimum Quality Lubrication**;** ND, Nano Diamond**;** NMQL, Nano Minimum Quality Lubrication; NP, Nano- Particles; SWCNT, Single Walled Carbon Nano-Tube.

I. INTRODUCTION

The interest of the ongoing serious world in assembling territory is efficiency ought to be high, quality ought to be acceptable and bed ought to be as low as could be expected under the circumstances. Thus, for accomplishing these requests handling parameters like cutting rate, long periods of machine work ought to be expanded which thus requires some investment and high measure of warmth age happens in machine zones because of which temperature of machine or machine zone rises and burst condition can happens [1]. Thus the utilization of conventional coolant happens in metal removal process so as to build efficiency, work quality, and so on however we notice that traditional liquids just acts oil yet decline in temperature didn't happened and furthermore ordinary liquid produce poor impact on heath of worker and environmental condition [2]. So for expanding the thermal conductivity rate macro or micro sized particles are utilized in traditional liquid so these particles expansion in customary liquid diminished down the temperature yet some issue emerges with them which are as following:

— Clogging of particles among instrument and work piece interface

— Pressure drop and Rough surface completion because of stopped up particles among device and work piece.

So the need of nanometered size ($<10^{-9}$) particles emerges as they are exceptionally little in size consequently no clogging and better surface finish obtained [3]. The expansion in thermal conductivity relies upon nanoparticles materials, sizes and focuses. Nanoparticles have increasingly surface region to-volume ratio; 1 nm round particles have surface zone to-volume proportion 1000 time more prominent than that of 1 μm particles [4].

Nanofluid- Nanofluid is the combination of base fluid or conventional fluids (water, mineral oil, vegetable oil, glycol, etc.) we are using for our lubrication in our traditional time with the nano-sized particles i.e. the particles of size 10^{-9}m (Metal oxide: Aluminium oxide, etc, Stable metal: Cu, Au, Carbon: carbon nanotubes, diamond, graphite, fullerene, Polymer: teflon) [4]. The science behind the nanofluid is Nanoscience or nanotechnology which relates with the study of individual objects at atomic or molecular scale.

Nanoscience and nanotechnology is the study of extremely small things and can be used across all others science fields such as chemistry, biology, physics, materials science and engineering. The first ever concept was presented in 1959 by Professor of Physics Dr. Richard P. Feynman in which he told scientist that they can control individual atoms and molecules. The term "Nano-Technology" had coined by Norio Taniguchi in 1974. The nanofluid was introduced by Choi, and after that a lot of research is been done in this field [5].

Types of nanofluid- They can be classified into two primary classes: single material nanofluids and half and half nanofluid.

1. Single material nanofluid: A liquid suspended with nanoparticles (under 100nm size) of metallic or non-metallic substance consistently and steadily suspended in ordinary liquid is known as nanofluids. Wide scope of nanoparticles in different shapes, for example, round, barrel shaped and so forth is made from unadulterated metals (Au, Ag, Cu, Fe), metal oxides (CuO, SiO_2, $Al2O_3$, TiO_2, ZnO, Fe_3O_4, Fe_2O_3, MgO), carbides (SiC, TiC), nitrides (AlN, SiN) and various kinds of carbon (precious stone, graphite, single/multi divider carbon nanotubes) by various synthetic procedures [6]. Conventional fluids utilized as base liquids are water, ethylene glycol, refrigerants and motor oil. Nanoparticles can be blended in with various base liquids in various fixation proportions. Henceforth, upgrade of warm execution of warmth pipe utilizing nanoparticles primarily relies on parameters, for example, type, size, shape and grouping of nanoparticles and base liquid [7].

2. Hybrid nanofluid: This nanofluid is formed by the combination of two or more nanoparticles into the basefluid like CNT–Cu/H_2O. Thermal conductivities of metal oxides, for example, $Al2O_3$, SiO_2 and TiO_2 are lower than those of metals like silver, copper and gold or carbon mixes, for example, precious stone, carbon nanotubes and graphene. Conglomeration of unadulterated metal like Ag, Cu and oxides like CuO are higher than oxides like Al2O3 because of higher mass thickness[8]. As of late, as nanotechnology has quickly grown, low warm conductivity and security issues of nanofluids could be overwhelmed by mix of more than one part nanoparticles to accomplish synergetic impact which is named as composite/crossover nano-added substance. A suspension with organizations of half and half nano-added substances named as 'hybrid nanofluid' prompts an expanded thermal conductivity and steadiness which encourages heat move upgrade [9]. Example- Al_2O_3-Cu/DI water, Cu-TiO_2/water, Graphene oxide, and graphite-2H/amorphous carbon, MWCNT Fe_3O_4/water, Graphene Nan platelets -Silver (GNP-Ag)/DI water, Cu-TiO_2/Water/EG, Al_2O_3–Cu/water, etc.

Preparation of Nanofluid- 2 method for the preparation of nanofluid.

3. Two-Step Method- In this method, fine particles of material as nanoparticles is taken and they are directly mixed into the base fluids but the directly mixing cause aggregation of nanoparticles in basefluid. So, to avoid this surfactant is added into the nanofluid and this mixture is put on for ultrasonication (few hours) for proper mixing and then we get Nanofluid [10].

Advantages: Suitable for mass production.

Disadvantages: Aggregation is the problem in this method.

4. One-Step Method- In this process, nanoparticles as bulk solid is taken and suspended into the basefluid and hence dissolving of nanoparticles into basefluid takes place and no aggregation is here. This method takes more time than the two step method hence not suitable for the mass production of nanofluid [11].

Advantages: No aggregation takes place so there is no use of surfactants over here.

Disadvantages: Dissolving of nanoparticles into the basefluid takes time hence not suitable for mass production.

NP's in basefluid together reduces the tool wear, thrust force, surface roughness, power consumption, cutting temperature and coefficient of friction. But one problem arises that the use nanofluid in bulk form is not possible as they are taking about 15-18% of total manufacturing cost so a lubricating technique to be developed in order to use the lubricant/coolant (i.e., nanofluid) in adequate amount and that lubricating technique is named as Minimum Quality Lubrication (MQL[2]).

Lubrication Technique: After removal of the problem of dry machining → conventional fluid→ macro/micro particles → nano particles, another problem raised i.e., method of application of nanofluid in order to reduce pollution to environment and reduction of cost of manufacturing as coolant and lubricant consumes 15-18% of total cost [5].

So a strategy developed named as Minimum Quality Lubrication (MQL) in which coolant is blended in with packed air or wet fog and ideal splashing is done over instrument and work piece interface. This is useful for higher speed activity as opposed to bring down speed [2]. Some advantages of MQL are as follows: Reduction in machining temperature, Reduction in surface roughness, Reduction in cutting force, Reduction in tool wear (flank wear also), Metal removal rate increased

For all cooling draws near, the flank wear expanded somewhat as the quantity of penetrated gaps expanded. Be that as it may, the flood coolant indicated higher flank wear as shown in Fig.1 compared to the unadulterated MQL and MQL-nanofluid. High apparatus wear movement on the flank face was seen when flood cool-insect was utilized in light of the fact that flood coolant couldn't without much of a stretch infiltrate the smaller scale gap because of its little size and subsequently couldn't diminish the high temperature [1]. Along these lines, because of the rubbing and high temperature, the flood coolant gave generally higher flank mileage on the flank face. Then again, the MQL fog might have the option to infiltrate the little opening; while the boring activity was played out, the MQL entered the bored gap and shaped a meager oil film between the inward surface of the penetrated gap and the apparatus [5]. The most minimal device wear saw with MQL-nanofluid contrasted with flood and unadulterated MQL can be ascribed to the arrangement by nanofluid of a tribo-film between the cutting apparatus and the internal bored opening. This tribo-film decreases the scouring activity because of the moving impact, along these lines diminishing the prompted erosion.

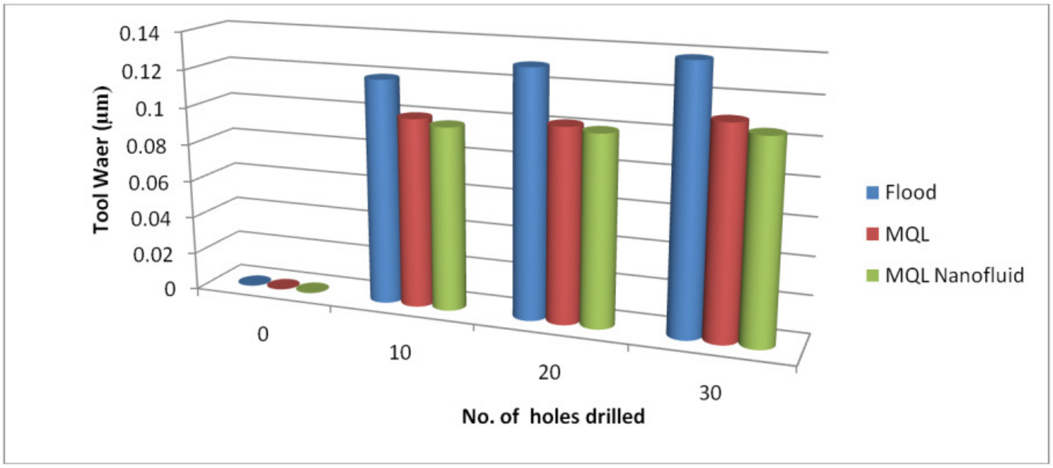

Fig. 1. Tool wears progression during holes drilling with Flood, MQL, MQL Nanofluid [12].

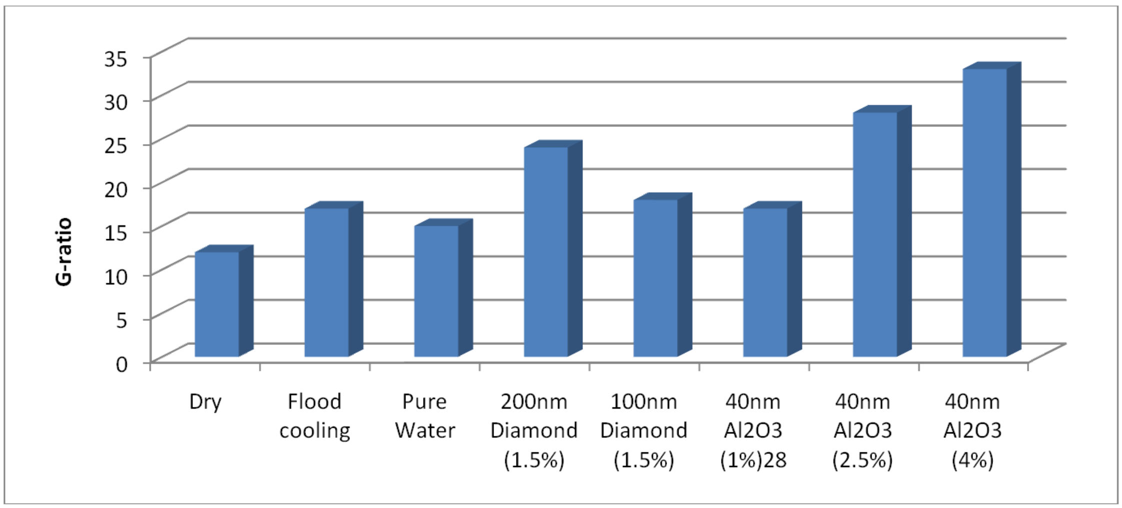

Fig. 2. G-ratio variation with different method of lubrication [14].

During drilling compressed air MQL is removed with wet mist MQL hence surface finish of hole increased and flank wear of tool reduced and in deep hole drilling easily chip removal takes place with this MQL technique. The table shows the graph of tool wear progession during drilling of holes with Flood, MQL, MQL Nanofluid [12].

By and large, two distinct classifications of the conveyance framework were utilized in MQL innovation viz. interior and outside conveyance. In an inner conveyance framework, the air and oil were stirred up inside the spout and showered to the machining zone through an extraordinarily manufactured single/double channels. On the opposite side, in an outside conveyance framework, an atomizer is utilized to set up the airborne and convey remotely to the machining zone structure and assessment of an atomization-based cutting liquid splash framework in turning [13].

While in grinding, effective utilization of cutting fluid is done by setting nozzle angle and distance of nozzle from which spraying of nanofluid is done on work piece surface. Hence surface roughness and grinding force reduced and G-ratio increases. So in this way grinding reduces the cost of manufacturing and increase the productivity and output of machining process [2].

[14] G-ratio approximate variation with different method of lubrication is show in Fig. 2 which shows that G-ratio is very less in dry machining as there is no coolant and lubricant and same happen with flood cooling and pure water also but as we start using nanoparticles (Al_2O_3) and (Diamond) we are getting G-ratio higher than dry or pure water.

II. INFLUENCE OF NANO‐ ENRICHED CUTTING FLUIDS

Specialists saw that blending of nanometer-sized particles in the base liquid has high potential to improve the different properties of the blended liquid. Parameter of machining execution relies mostly upon the conduct of nanofluid under fluctuated working/machining conditions. The different parameters resemble Nanoparticle's fixation in base liquids, Nanoparticle's shape, size, splash spout direction, separation of shower and grease mode. For ideal execution, thought of every one of these parameters (suitable worth) during the choice of the nanofluid is vital. Based on the available literature, application of nanofluids and influence of their parameters on various metal removal processes are discussed in the following:

Table 1: Effect of Nanofluid in Machining when Nanoparticles mixed with basefluid.

Authors	Nano-Particles	Base-fluids	Outcomes
[12, 15]	$Al2O_3$	TRIM E709 emulsifier, Vegetable oil, Palm oil	— When TRIM E709 emulsifier as mineral oil is used it increased surface roughness but work piece temperature decreased by 20-30% as that in dry and plain emulsifier and when vegetable oil are used they also enhanced the surface finish. —NP's creates ball bearing effect between tool and work piece and hence reduces friction, thrust force, burr formation, and increased micro drilled holes quality. — Temperature, tool wear, cutting force and surface roughness were decreased with 6vol% of Al2O3 particles for machining Inconel 600 alloy. — Deduction of 25.5%, 5.27% and 28% in surface roughness, tool wear and cutting force respectively in turning AISI 1040 Steel when we are using 1vol% of Al_2O_3 — The cutting temperature is continuously decreasing and minimum (144.01 ℃) as concentration of (%) of Al_2O_3 is increasing up to 2% whereas the maximum temperature (145.78 ℃) was observed at 5% Al_2O_3 concentration. — Palm oil is best base fluids among them.
[16, 19]	Ag	Oil, Water, Deionized water, Distilled Water	— 0.5vol% Ag NP's reduces: — Temperature, surface roughness & cutting forces. — Deionized water gives better surface finish than distilled water.
[8], [20]	Au	Water, Toluene	— Small volume fraction of Au in toluene increases heat transfer rate.
[8, 21, 24],	Cu	Water, EG, Calcium based grease	— The heat transfer rate or thermal conductivity enhancement (%) of ethylene glycol (EG) is more than simply by water as a basefluid. — Smaller the concentration better the surface finish obtained.
[21, 25, 27]	CuO	Water, Calcium based grease, Canola oil	— By use of Cu and CuO, lower pressure drop compared to base fluid. —Smaller the concentration better the surface finish obtained. —CuO with Canola oil nanofluid MQL grinding, the rolling action of nanoparticles generates a smooth surface even at high depth of cut and linear velocity of work piece.
[28, 31]	Nano-Diamond with 30 mm. diameter.	Paraffin oil, Vegetable oil	In Micro-drilling of Al 6061, both oil with ND decreased the drilling torque & nearby twice the no. of hole drilled. — Paraffin oil is more effective than Vegetable oils. — 1 & 2vol% of ND reduces the torque, force and cavity formation and increases the life of tool. — 4vol% of ND reduces the power consumption and torque during process.
[32, 34]	Graphene or MWCNT, Nano-graphite (0.3 wt %)	Castrol Clearedge 6519, Deionized water, Eco-friendly oils like coconut oil, sesame Oil and mustard oil.	— Cutting temperature and cutting forces reduced to a great extent when graphene is used rather than MWCNT The use of graphene in EDM process improved the MRR, surface roughness, and TWR is 20.1%, 14%, and 2%, respectively. — The nano-graphite particles are having good stability in the sesame oil. — Nano-sesame cutting fluids are having better surface roughness properties.
[35, 38]	TiO_2	Soluble oil, Water, Karanja oil (100ml) with 0.03 wt% Ti02, Deionized Water	— Increases the cooling, lubricating and heat transfer coefficient. — As particle size reduced, heat transfer increases. At 21nm we get 2-20% % 15nm we get 33% thermal conductivity enhancement. With use of Karanja oil we get the peak tool temperatures reduced by 52% as compared to dry, i.e., 220–105 ℃ and an increase in surface finish quality of the average roughness by of about 50.7%. — 2.5vol% produce lowest tool wear in milling.
[39, 44]	SiO_2	Water, methanol, ECOCUT SSN 322 oil, Sol Cut, Mineral oil	— Lowest tool wear and very fine surface finish obtained at 0.5 wt% SiO_2 in basefluid. A thin layer of protective film formed between tool and work interface and hence minimize surface roughness. — Minimum cutting forces and temperature at 0.2 wt% of SiO_2.
[40, 45]	ZrO_2	Water, EG, Soybean oil	— The use of ZrO2 NP's in EG gives high value of thermal conductivity enhancement (%). 6vol% nanofluid has less energy consumption and grinding force value and ZrO2 behaves as bearing during grinding.

[46. 50]	MWCNT	Water, EG, Synthetic Engine oil, SAE 20W40 oil, Deionized Water	— Cutting fluids thermal conductivity increases rapidly as MWCNT is added in base fluid. Smaller the conc. of particles in the base fluids better the surface finish obtained as chances of clogging of particles reduces in small concentration.
[18]	ZnO	Deionized Water	— Spreading and lubricating property of ZnO is good hence better surface finish obtained. — Spreading property and lubricating property of ZnO is good and hence grinding is done properly.
[51]	hBN	Oil	— At 80m/min cutting speed, high tool life (44.89 min) and low tool wear and surface roughness (0.497µm).
[52]	Carbon NP with dispersant	-	— Carbon NMQL conditions can provide excellent lubrication and cooling, which lead to high surface quality, small grinding forces and minor subsurface damage as compared to the dry, flood and MQL grinding conditions,
[53]	Boric acid, MoS_2 with micro and Nano particle, CNTs & MoS_2	Coconut oil, Seasme oil, Soybean oil, Palm oil, rapeseed oil, Ester oil	— Nanofluid performs better than micro-fluids in decreasing cutting force, cutting temperature & surface roughness. — Soybean oil was found with most better lubricating condition. — Decreased in specific energy & lubricating property increased rather than pure ester oil in grinding.
[54]	Any NP	Vegetable oil vs. Mineral oil	— The layer of fatty acid facilitates a better lubrication layer and reduces the friction between work tool interfaces and results the lower energy consumption during machining.

During the traditional machining, we are not using any coolant or lubricant so there machine temperature increases to a high range but when we start using conventional fluids they only acts lubricant but decrease in temperature did not occurred so macro or micro particles are used in conventional fluid, So the need of nanoparticles arises as they are very small in size hence no clogging and better surface finish obtained. The various properties that are enhanced as shown in Table 1 are described as:

Surface Roughness reduction- By using 6% Al_2O_3 with vegetable oils for machining Inconel 600 alloy but for AISI 1040 Steel only 1% Al_2O_3 reduces surface roughness by 25.5%, 0.5 vol% Ag and ZnO in deionized water, 0.5 wt% of SiO_2 in base fluid, TiO_2 in Karanja oil and CuO in Canola oil, hBN with various oils reduces the surface roughness at a great extent because NP's acts as bearing between the machining parts and tools. The best surface quality (Ra=0.497 µm) in cooling conditions is happened in nano-MQL containing 0.5 vol% hBN, while the most exceedingly terrible surface quality is found in dry machining. Improvement in surface quality is normal. Be that as it may, with the utilization of nanofluid, the improvement in surface quality was progressively self-evident.

Lubricating Property Enhancement: This property enhancement is done by the combination of various nanoparticles in basefluid as CNT and MoS_2 in ester oil increased lubrication rather than simple ester oil, Carbon NP's in dispersant. The nano-added substances hold the oil particles, forestalling the immediate arrival of the cutting oil from the cutting zone, and along these lines it greases up better.

Thermal Conductivity Enhancement: NP's have large surface area to volume so heat transfer rate is very high by combination of Cu in ethylene glycol, Au in toluene, TiO2/MWCNT in basefluid like oils etc. Thermal conductivity of nanofluids differs with the size, shape, and material sort of nanoparticles. For instance, nanofluids with metallic nanoparticles were found to have a higher thermal conductivity than nanofluids with non-metallic (oxide) nanoparticles. The littler the molecule size, the higher the thermal conductivities of nanofluids. Besides, nanofluids with circular shape nanoparticles show a littler increment in thermal conductivity contrasted and the nanofluids having round and hollow (nano-pole or cylinder) nanoparticles

Tool Wear Reduction: Due to high rate of heat transfer, there is no chances of Built-Up Edge and hence wearing of tool reduced by combination of Graphene/hBN in oil, Carbon NP's in dispersant. In three different MQL methods (Pure MQL, 0.5 vol% nano MQL and 1 vol% nano MQL), the minimum amount of wear is obtained in nano-MQL containing 0.5 vol% hBN. It reduces the amount of wear by about 43% and highest tool wear obtained in dry machining.

Low Energy Consumption: By the combination of CNT and MoS_2 with ester oil, 6vol% of ZrO_2 in oil, 4vol% of ND in vegetable oils. Reduction of around 5 to 25% in machining force was achieved using synthetic ester coolant due to its smaller particle size and low frictional coefficient and as machining force reduced then the consumption of energy is also reduced.

Table 2: Property enhancement of Base-Fluids with different Nanoparticles.

Authors	Nano-particle	Base-fluids	Particles Size(nm)	Volume fraction (%)	Thermal conductivity enhancement (%)	Outcomes
[55], [56], [57], [58], [59], [35], [60] [59], [21], [41], [59]	Al_2O_3	Water	30	0.01-0.3	44	The thermal conductivity enhancement (%) of alumina with ethylene glycol at less particle size is more so use of small particle size should be considered. • Good surface finish obtained at high thermal conductivity enhancement. • By use of small size particle clogging will not take place.
			38.4	4.0	9.4-24.3	
			36	3.1-9.0	15.0	
			47	4.0	29	
			50	5.0	4.4	
		EG/Water	120	1.0-4.0	5.0-20	
		EG	28	5.0	24.5	
			50	5.0	14.2	
			45	0.5	8.5	
		Methanol	40-50	0.5	10.74	
		Paraffin	50	5.0	11.4	
[8, 21-23]	Cu	Water	35	0.05-0.3	18-68	The heat transfer rate or thermal conductivity enhancement (%) of ethylene glycol (EG) is more than simply by water as a basefluid. • By use of Cu and CuO, lower pressure drop compared to base fluid. The higher thermal conductivity of nanofluids with higher volume fraction of solid nanoparticles.
			80	0.5	24	
		EG	20	1	48-70	
			30	7	9.13	
[21], [25], [26] [27], [61]	CuO	Water	31	3.0	17	
			63	6.0	17	
			100	7.5	52	
		Distilled water plus 20 wt.% canola oil	50	0.15, 0.25, and 0.35	-	
		SWCNT	2	0.02%, 0.05%, 0.1%, 0.25%, 0.5% and 0.75%,	36.2	
[35], [36], [62]	TiO_2	Water	21	1.0-8.0	2.0-20	• As particle size reduced, heat transfer increases. • Ethylene glycol-based TiO2 nanofluid increased the tool life by 40.55 %.
			15	5.0	33	
		EG	155	1.5	-	
[39], [40], [41]	SiO_2	Water	12	1.1-2.4	1.1	• Lowest tool wear and very fine surface finish obtained at 0.5 wt% SiO_2 in basefluid.
			25	2.0	40	
		Methanol	10-20	0.5	14.29	
[40], [53]	ZrO_2	Water	44-105	6.0	17.2-21.6	• The use of ZrO_2 NP's in EG gives high value of thermal conductivity enhancement (%).
		EG	20	0.0-0.2	60	
[16], [17]	Ag	Oil	5.0	0.5	7-17	• 0.5vol% Ag NP's reduces: Temperature, surface roughness & cutting forces.
		Water	60-80	0.1	3.2-16.5	
[8], [20]	Au	Water	15	1.4	8	• Small volume fraction of Au in toluene increases heat transfer rate.
		Toluene	1.65	0.003	14	
[46], [47]	MWNT	Water	10-30	1.0	7.0	• Cutting fluids thermal conductivity increases rapidly as MWCNT is added in base fluid.
			100	0.6	38	
		EG	20-50	1.0	12.4	
		Synthetic Engine Oil	20-50	2.0	30	
[63]	Al_2O_3 MoS_2 Graphite	-	40 40 40	3 wt%	-	• Graphite NP revealed the lowest cutting temperature than the Al2O3 and MoS2.

The study of various nanoparticles with base fluid to get various property enhancements as the thermal conductivity enhancement (%) is shown in Table 2. Since the thermal conductivity of solids might be a few sets of extent higher than the thermal conductivities of traditional warmth move liquids, for example, water, oil or ethylene glycol (EG), the expansion of exceptionally leading strong particles to a liquid can possibly build the compelling thermal conductivity of the liquid. Factors, for example, molecule parameters (molecule type, stacking, size and shape) and ecological parameters (base liquid, pH worth, temperature and the standing time) impact thermal conductivity. The deliberate thermal conductivity of Al_2O_3-water nanofluid is dependent on temperature and nanoparticles volume portion. It is indicated that the thermal conductivities of Al_2O_3-water nanofluids have been expanded over those of unadulterated water. The thermal conductivity of nanofluid increments with increment in the temperature and this expansion is progressively articulated at higher nanoparticles volume divisions. Thermal conductivity of water increments because of expansion of little focus (0.1 w/w %) of TiO_2 nanoparticles what's more, it increments with temperature. It is likewise evident that the improvement of the thermal conductivity of nanofluids comparative with base liquid (water) increments as the temperature increments. This is intriguing as nanofluids can perform better warmth move (like cooling) at high-temperature conditions. The expansion of nanotubes into a liquid prompts considerable improvement of thermal conductivity. The thermal conductivity improvement increments with the expansion in nanotubes stacking, yet is diminished with thermal conductivity increment of the base liquid. The nanofluids containing little vol% of nanoparticles have fundamentally higher (up to multiple times) thermal conductivity than the base fluids without nanoparticles. For nanofluids utilizing a similar measure of (ZrO_2) nanoparticles, the conductivity of the ethylene glycol-based nanofluid was consistently higher than that of water-based nanofluid. This is potentially on the grounds that ethylene glycol is more viscous than water and the particles are increasingly steady. Hence from various paper studies we conclude that the use of mineral oils, vegetables oil, EG, etc. is much better than simply using water for property enhancement.

Table 3: Effect of Nano-Particles for Surface Roughness in Metal Removal Process.

Authors	Nano-Particle	Base-Fluid	Size(Nm)	Concentration of NP's (%)	Surface Roughness (µm)	Outcomes
[64-74]	Al2O3	Deionized Water	40	0.2	0.488	The surface roughness was highest (0.321 µm) when 0.5% Al2O3 nano-particles were mixed with palm oil. Then at 2.5% Al2O3 the minimum surface roughness (0.262 µm). Then again the surface roughness increased and reached 0.312 µm.
				1.2	less than 0.20	
				2.5	less than 0.25	
				5.0	less than 0.19	
			60	0.75	0.20	
		Soybean oil	20	1.5	less than 1.0	
		Vegetable oil	30	1wt%	0.354	
		Canola oil	80	3.0	less than 0.24	
		Water	40	1.0	less than 0.72	
		Palm oil	50	2.0	0.301	
		Palm oil	-	0.5	0.321	
		Palm oil	-	2.5	0.262	
		Servo-cut S	less than 100	1.0	less than 0.57	
		TRIM E709 Oil	less than 100	1.0	less than 0.60	
		Sol Cut (SO)	less than 50	0.2	1.285	
[75], [75], [76], [77], [78], [24]	MoS2	Paraffin oil	50	2.0	0.70	0.5wt% gives the best surface condition for machining but as we increase concentration up to 1 wt% surface roughness also increases.
		Palm oil	50	2.0	0.90	
		Colza oil	50	2.0	0.72	

		ECO CUT HSG 905S	20-60	0.5	0.39	
		ECO CUT HSG 905S	20-60	0.5	0.223	
		Calcium based grease	1000	10.0	less than 3.8	
[48-50]	MWCNT	SAE 20W40 oil	10-20	2gm in 1000ml	0.057	• Smaller the conc. of particles in the base fluids better the surface finish obtained as chances of clogging of particles reduces in small concentration.
			10-20	10 gm in 1000ml	0.4478	
		Deionized Water	50	1.0	less than 0.38	
		SAE 20W40	10-20	10 gm in 500ml	0.19	
[79]	SWCNT	Water soluble oil	1-2	2gm in 1000ml	0.1791	
[80], [81]	CNT	SAE 20W40 OIL	1-2	2gm in 1000ml	0.1339	
		Synthetic oil	30	2.0	0.465	
[42], [43], [44], [82]	SiO2	ECO CUT SSN 322 oil, Sol Cut, Mineral oil	5-15	1.0	0.34	A thin layer of protective film formed between tool and work interface and hence minimize surface roughness.
			5-15	1.0	1.0	
			less than 100	1.5	1.59	
			5-15	1.0	0.75	
[29]	ND	Paraffin oil	30	2.0	less than 0.11	• Paraffin oil is more effective than Vegetable oils.
[24]	Cu	Calcium based grease	200	10	less than 3.0	• Smaller the concentration better the surface finish obtained. CuO Nanofluid with soluble oil reduced surface roughness and machining force by 49% and 24% respectively
[24], [71], [27]	CuO	Calcium based grease	48	10	less than 3.5	
		Water	40	1.0	less than 0.61	
		Soluble oil	-	1.0	-	
[18]	ZnO	Deionized Water	10	0.5	0.42	Spreading and lubricating property of ZnO is good hence better surface finish obtained.
[18], [19]	Ag	Deionized Water	25	10	0.38	-
		Distilled Water	-	0.5	less than 6.0	
[83]	Nano boric acid	SAE-40 oil	50	0.5	more than 2.5	• Reduction in cutting temperature. • Increase in tool life & surface finish.
		Coconut oil	50	0.5	less than 3.5	
[51]	hBN	Oil	-	0.5vol%	0.497	At 80m/min cutting speed, high tool life (44.89 min) and low tool wear and surface roughness (0.497µm).

One of the best criteria to define a good machining is the surface quality of work piece which is machined is described in Table 3. Surface quality is defined with respect to surface roughness (i.e. the amount of deviation in the direction of normal vector of an original surface from its absolute form). When deviation is more means rough surface and when less means smooth surface which is the aim of machining to achieve [84]. The advantage of the use of nanoparticles in conventional fluid is that the holes or scratches present on the work piece and tool are occupied by or filled up by the nanoparticles finer size to get uniform surface and gives better surface finish by reducing friction and cutting temperature. Nanofluids have better wetting and lubricating property so that the rate of heat dissipation increase and good surface finish obtained and surface roughness reduced.

The study of various nanoparticles for surface roughness in metal removal process as the surface roughness was highest (0.321 μm) when 0.5% $Al2O_3$ nano-particles were mixed with palm oil and then at 2.5% $Al2O_3$ the minimum surface roughness (0.262 μm) and then again the surface roughness increased and reached 0.312 μm[15], and Surface roughness is plotted in the Fig. 3 at different concentration of Al_2O_1 with palm oil:

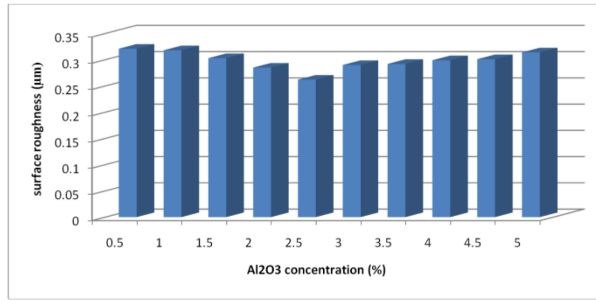

Fig. 3. Surface roughness at different concentration of Al_2O_3 with palm oil [15].

Smaller the conc. of particles in the base fluids better the surface finish obtained as chances of clogging of particles reduces in small concentration and in MWCNT, SWCNT and CNT, the MWCNT is the best nanoparticles with various basefluid. Hence a thin layer of protective film formed between tool and work interface by using nano sized particles in base fluids and hence minimize surface roughness.

Table 4: Study of the Effect of Nanofluid for various properties enhancement in different Machining Process.

Process	Authors	Nano Particles/Base Fluid	Concentration of NP's in Base Fluid/Size (nm)	Outcomes
Drilling	[69], [12]	Al2O3/Soybean oil & Vegetable oil	1.5vol%/20 & 18	Soybean oil-Drilling torque and thrust forces as compared to dry and wet drilling situations decreases and no. of drilled holes increases. Vegetable oil-NP's creates ball bearing effect between tool and work piece and hence reduces friction, thrust force, burr formation, and increased micro drilled hole quality.
	[85]	TiO2/Soluble oil	0.3, 0.6, 1.0 wt%/20	• Increases the cooling, lubricating and heat transfer coefficient.
	[86]	MWCNT/Hydrogenated oil	22, 50, 100 ppm/10-12	• Cutting fluids thermal conductivity increases rapidly as MWCNT is added in base fluid.
	[87] [30] [31]	ND/Paraffin oil and vegetable oil	1.0, 2.0, 4vol%/30 & <100	• Paraffin oil-1% ND • Vegetable oil-2% ND Reduces the drilling torque and thrust forces. • 1 & 2vol% reduces the torque, force and cavity formation and increases the life of tool. • At 4vol% reduces the power consumption and torque during process.
Milling	[15]	Al2O3/Palm oil	0.5%, 2.5%/-	The surface roughness was highest (0.321 μm) when 0.5% Al2O3 nano-particles were mixed with palm oil. Then at 2.5% Al2O3 the minimum surface roughness (0.262 μm). Then again the surface roughness increased and reached 0.312 μm.
	[42] [88]	SiO2/ECOCUT SSN 322 mineral oil	0.2, 0.5, 1.0 wt%/5-15	• Minimum cutting forces and temperature at 0.2 wt% of SiO2. A thin layer of protective film formed between tool and work interface and hence minimize surface roughness.
	[78]	MoS2/ECOCUT HSG 905S oil	0.2, 0.5, 1.0 wt%/20-60	0.5wt% gives the best surface condition for machining but as we increase concentration up to 1 wt% surface roughness also increases. • Minimum forces at 1wt% MoS2, 4 bar and 30º nozzle angle, • Best surface finish at0.5wt%, 4 bar and 60º nozzle angle.
	[89]/[38]	TiO2/Deionized Water	0.5, 1.5, 2.5, 3.5, 4.5vol%/40	• Lesser chips • Higher cooling rate • Good lubrication • 2.5vol% produces lowest tool wear.
Turning	[74] [90]	Al2O3/Sol Cut (SO) & Deionized Water	0.2, 0.4, 0.6 wt% & 0.1vol%/<50 & 40	• For Sol Cut- Cutting forces and tool wear minimizes due to low μ value of Al2O3. For Deionized Water • Less tool wear • Chip curling minimized • Low coefficient of friction
	[91]	Al2O3 Al2O3-MoS2/-	-	The use of Al-MoS2 hybrid nano-cutting fluid give reduction of 7.35%, 18.08%, 5.73%, and 2.38% respectively, in cutting force, feed force, thrust force and surface roughness compare to Al_2O_3 mixed nanofluid.
	[51]	hBN/Oil	0.5vol%/-	• At 80m/min cutting speed, high tool life (44.89 min) and low tool wear and surface roughness (0.497μm).
	[92]	Graphite/LB2000 PriEco6000	0.1, 0.5 wt%/35	• Even at high speed, less value of cutting forces and temperature obtained.
	[93]	Al2O3, MoS2, Graphite/Vegetable oil	3.0 wt%/40	• Good performance recorded relative to other as thermal carrying capacity of graphite is high.
	[70]	Al2O3/Vegetable oil	1wt%/30	• The minimum surface roughness was 0.354 μm and power consumption is 0.528 kW.
	[82]	SiO2/Mineral	0.2, 0.5 1.0	• Lowest tool wear and very fine surface finish obtained at 0.5 wt% SiO_2 in basefluid.

		oil	wt%/5-15	
	[37]	TiO2/Karanja (bio) oil (100ml)	0.03wt% /-	The peak tool temperatures reduced by 52% as compared to dry, i.e., 220–105 ℃ and an increase in surface finish quality of the average roughness by of about 50.7%.
	[94]	CuO/Water	0.5, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0vol%/<100	• 1% CuO conc. gives no variation in temperature profile and hence tool life increases.
	[19]	Ag/Distilled Water	0.5vol%/-	• 0.5vol% Ag NP's reduces: • Temperature, surface roughness & cutting forces.
	[64]	MWCNT/Distilled Water	0.2vol%/10-20	• Reduction in cutting forces & surface roughness by 5-8% & 9-22% respectively.
	[83]	Nanoboric acid/SAE-40 oil and coconut oil	0.25, 0.5, 1.0, 2.0, 3.0, 4.0, 5.0 wt%/50	• Reduction in cutting temperature. • Increase in tool life & surface finish.
	[95]	Nanoboric acid/Coconut oil	0.25, 0.5, 0.75, 1.0 wt%/50	• Reduction in cutting temperature. • Increase in tool life & surface finish.
	[24]	MoS_2 GF Cu CuO/Calcium-based Grease	1, 3, 5, 10, 20 wt%/1000 0.2, 0.5, 1, 3, 5 wt%/150 1, 3, 5, 10, 20 wt%/200 1, 3, 5, 10, 20 wt%/48	Among all NP's with various conc., the 10 wt% Cu particles have lowest value of tool wear and finest surface finish.
Grinding	[29]	Al2O3, ND/TRIM E709 oil, Paraffin oil	1.0 wt%, 2.0, 4.0vol%/<100, 30 and 150 ml of each	With TRIM E709 oil, wearing of wheel reduced, so surface finish increase and temperature decrease. ND particles are much better than Al_2O_3. Due to its good lubricating property grinding force reduced.
	[96], [72]	Al2O3/Deionized Water, Palm oil	0.5 wt%, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4vol%/10,50	• 0.5 wt% Al2O3 with water improve heat carrying capacity as compare to water. • Energy consumption and force ratio reduced at 1.5vol%.
	[97]	Al2O3, MoS2/Deionized Water, Canola oil	1.0 wt%, 1.0vol%/10, 70	• Lee coefficient of friction. • Reduction in grinding force. • Grinding temperature reduced.
	[98]	Graphite/Distilled water plus 20 vol. % canola oil	0.15, 0.25, and 0.35vol% /32	0.35 vol. % graphite nanofluid MQL results in surface roughness reduction of 48.77% along and 43.55% in the grinding direction
	[99], [100], [101]	MoS2/Paraffin oil, soybean oil and CANMIST oil, Palm oil, Rapeseed oil	5.0,2.0, 20, 8.0 wt%/<100, 50	• As number of MoS2 particle increases, the grinding ratio increases. • Less coefficient of friction obtained • G-force and G-ratio increased • Lowest value of temperature obtained at 8 wt% of MoS_2 and fore ratio also reduced. • Best lubricating property with MoS_2 NP.
	[80]	CNT/SAE 20W40 oil	0.2vol%/1-2	• Average surface roughness and Root Mean Square value improved by adding CNT basefluid.
	[48], [50]	MWCNT/SAE 20W40 oil, Deionized Water	0.2, 0.6, 0.8, 1.0, 1.2, 1.4vol%/10-20, 50	• With SAE 20W40 oil- Nano-sized surface quality improved. With Deionized Water - Wheel wear reduced and hence material removed from work piece increased, G- force reduced and good surface finish obtained.
	[18]	Ag, ZnO/Deionized Water	10, 20, 30vol% of colloidal Ag, 0.01, 0.1 0.5vol% ZnO/25, 10	• Spreading property and lubricating property of ZnO is good and hence grinding is done properly.
	[81]	CNT-MoS2/Synthetic oil	2, 4, 6, 8,10, 12vol%/30	• Mixing of CNT-MoS2 gives good surface finish and G-ratio as compare to single nanofluids.
	[45]	MoS2, ZrO2/Polycrystalline Diamond, Soybean oil	2, 4, 6, 8,10vol%/50	6vol% nanofluid has less energy consumption and grinding force value and ZrO2 behaves as bearing during grinding.
	[52]	Carbon NP with dispersant/-	5 gm in 1000ml/-	Carbon NMQL conditions can provide excellent lubrication and cooling, which lead to high surface quality, small grinding forces and minor subsurface damage as compared to the dry, flood and MQL grinding conditions.

The tribological properties of the mixed fluid (NP's and base fluids) are improved by the addition of nanometer sized particle with base fluid [2]. By the study of various research papers, application of nanofluids and affect of their parameters on various metal removal processes are presented in Table 4 are as follows:

Drilling Process: Various parameters like forces, torque, power consumption, etc. are directly affected by the concentration of nanoparticles in micro-drilling process. MQL nanofluid reduces the tool rupture and increases tool life by lowering forces and torques. The addition of NP in basefluid with MQL increases the hole finishing and hence torque as well as power consumption reduced [30] . By using Al_2O_3 with Soybean oil and Vegetable oil we found that by use of soybean oil the quantity of drilled holes increased [69] but by vegetable oil the quality of drilled hole improved[12]. Nanoparticles create a ball bearing effect between the tool and work piece that reduce the friction and thrust forces and hence flank wear, the outer corner damage, and the breaking of the drilling tool reduced and efficiently drilling done by $Al2O_3$ nanofluid. As TiO_2 nanoparticles with concentration (0.3, 0.6, 1.0wt%) added in soluble oil, and the three condition of drilling is used: dry, with soluble oil and TiO_2 with soluble oil and they obtained that with TiO_2 in soluble oil the cooling(as TiO_2 increases the heat transfer rate so temperature reduced) and lubricating property between drill bit and work material increases and hence surface finish of hole is good. [85]. 1 & 2vol% of ND reduces the torque, force and cavity formation and increases the life of tool[30] and at 4vol% of ND reduces the power consumption and torque during process [31]. To measure Metal removal rate, drill force and torque with four parameters (diameter of drill bit, spindle speed, feed in hole direction, concentration of NP's) this machining started and get the torque and thrust force to its minimum value.

Milling process: By the application of various NP's in conventional fluid increases the milling performance in terms of lowering the power, forces and energy and the use of nanofluid with nozzle of thin jet and high pressure air, 25% reduction notice in consumption of oil [2]. Using 0.5vol% and 2.5vol% of Al2O3 in palm oil gives the surface roughness was highest (0.321 μm) when 0.5% Al_2O_3 nano-particles were mixed with palm oil and then at 2.5% Al_2O_3 the minimum surface roughness (0.262 μm) and after that again the surface roughness increased and reached 0.312 μm. 2.5% Al_2O_3 nano-particle concentration demonstrated much better machining behavior as compared to other lubricating medium [15]. [15] Cutting temperature graph regarding milling operation at different concentration of Al_2O_3 with operation parameters feed (0.2mm/tooth), depth of cut (1mm) and cutting speed (140m/min) is plotted below Fig. 4 and tells about the thermal dissipation property by different concentration of Al_2O_3 are

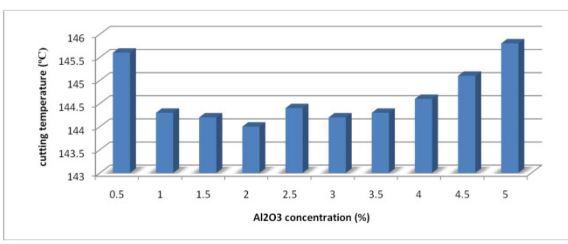

Fig. 4. Cutting temperature at different concentration of Al_2O_3 [15]

Turning process: As the concentration of NP increased in base fluids, surface finish improved due to the formation of a thin protective film between tool and work material surfaces and also by reduction of the coefficient of friction results decrement in cutting force and tool wear[74].

The use of Al-MoS_2 hybrid nano-cutting fluid give reduction of 7.35%, 18.08%, 5.73%, and 2.38% respectively, in cutting force, feed force, thrust force and surface roughness compare to Al2O3 mixed nanofluid [91]. 1vol% of $Al2O_3$ in conventional fluids increases the wetability rather than conventional fluid and pure water. While we are using TiO_2 with Karanja (bio) oil gives the peak tool temperatures reduced by 52% as compared to dry, i.e., 220–105 ℃ and an increase in surface finish quality of the average roughness by of about 50.7% [37]. Highest heat transfer rate is obtained with bio oil cooling method rather than by spray impingement or only with water. Increase in the spindle speed, air pressure caused reduction in average surface roughness, but as either feed or depth of cut increased average surface roughness also increased. Workpiece of reaction bonded silicon carbide material is operated by turning operation on lathe. Various NP's (MoS_2, GF, Cu, and CuO) with Calcium-based Grease base fluid with various composition gives the 10 wtº% Cu particles have lowest value of tool wear and finest surface finish. When surface area is less than or 400 mm^2 then surface roughness is lee but as surface area is above 400 mm^2 there is rapid increase in surface roughness [24]. When 0.5% wt. hBN NP's are used with oil based fluid then at 80m/min cutting speed, high tool life (44.89 min) and low tool wear and surface roughness (0.497μm). Nanofluids nano particles contain oils with themselves and they release them in the machining zone and hence better lubrication is done by Nanofluids. But when NP's concentration increased a limit then tool life and surface roughness degrades. [51]. When 1wt% of Al_2O_3 of size 30nm is mixed with vegetable oil then the minimum surface roughness was 0.354 μm and power consumption is 0.528 kW[70].

Grinding process: Conventional fluid has no or very less thermal conductivity and heat transfer rate and hence by the use of NP's in conventional fluid improve grinding performance by reducing surface roughness, temperature, grinding force and G-ratio as the NP's behaves as a ball bearing between wheel and grinding surface[67].

When Graphite (0.15, 0.25, and 0.35vol% and 32nm diameter size) is used with Distilled water plus 20 vol. % canola oil then 0.35 vol. % graphite nanofluid MQL results in surface roughness reduction of 48.77% along and 43.55% in the grinding direction and the application of graphite nanofluid MQL reduced the temperature of grinding at higher velocities of work piece. In graphite nanofluid MQL grinding, at extreme machining conditions the effective tribo- film formation in wheel-work piece interface gave a smooth surface, as 0.35 vol. % graphite nanofluid MQL results in surface roughness reduction of 48.77% along and 43.55% across the direction of grinding rather than flood cooling [98]. CNT (0.2vol% and 1-2nm diameter size) with SAE 20W40 oil used for grinding of AISI D3 tool steel work piece with vitrified alumina grinding wheel grinder results that average surface roughness and Root Mean Square value improved by adding CNT basefluid and increase in flash point by 10ºC and in fire point by 15ºC recorded as initial is 200ºC and 235ºC. both CNT and non- CNT basefluid experiment performed and they noticed that micro cracks disappear when CNT is used [48]. Carbon NP with dispersant (5 gm in 1000ml) used then Carbon NMQL conditions can provide excellent lubrication and cooling, which lead to high surface quality, small grinding forces and minor subsurface damage as compared to the dry, flood and MQL grinding conditions[52]. MWCNT (0.2, 0.6, 0.8, 1.0, 1.2, 1.4 vol %) NP is used with SAE 20W40 oil with 10-20nm diameter size results Nano-sized surface quality improved, and when Deionized Water having 50nm diameter size used it result wheel wear reduction and hence material removed from work piece increased, G-force reduced and good surface finish obtained and surface quality improved from micro level to nano level [48, 50].

III. CONCLUSIONS

This review paper presents a summary of some important published research works on application of various nanofluids in different metal removal process like drilling, milling, turning and grinding. The review article also describe the various parameters like Nanoparticle's concentration in base fluids, Nanoparticle's shape, size, spray nozzle orientation, distance of spray and lubrication mode. From literature review, it is found that various properties (surface finish, thermal conductivity, etc) are obtained at appropriate concentration only. Furthermore, NP's in basefluid together reduces the tool wear, thrust force, surface roughness, power consumption, cutting temperature and coefficient of friction.

The following conclusion drawn from the literature review-

— NP's creates ball bearing effect between tool and work piece and hence reduces friction, thrust force, burr formation, and increased micro drilled holes quality.

— 1 & 2vol% of ND in oil reduces the torque, force and cavity formation and increases the life of tool and 4vol% of ND in oil reduces the power consumption and torque during process.

— Lowest tool wear and very fine surface finish obtained at 0.5 wt% SiO_2 in basefluid and minimum cutting forces and temperature at 0.2 wt% of SiO2.

— Ethylene glycol-based TiO2 nanofluid increased the tool life by 40.55 % and 0.5vol% Ag NP's reduces: Temperature, surface roughness & cutting forces. NP's heat transfer rate or thermal conductivity enhancement (%) in ethylene glycol (EG) is more than simply by water as a basefluid.

— The surface roughness was highest (0.321 µm) when 0.5% Al_2O_3 nano-particles were mixed with palm oil and then at 2.5% Al_2O_3 the minimum surface roughness (0.262 µm) and then again the surface roughness increased and reached 0.312 µm. When 1wt% of Al_2O_3 of size 30nm is mixed with vegetable oil then the minimum surface roughness was 0.354 µm and power consumption is 0.528 kW.

— By using Al_2O_3 with Soybean oil and Vegetable oil we found that by use of soybean oil the quantity of drilled holes increased but by vegetable oil the quality of drilled hole improved. Nanoparticles create a ball bearing effect between the tool and work piece that reduce the friction and thrust forces and hence flank wear, the outer corner damage, and the breaking of the drilling tool reduced and efficiently drilling done by Al_2O_3 nanofluid.

— CuO Nanofluid with soluble oil reduced surface roughness and machining force by 49% and 24% respectively.

— When 0.5% wt. hBN NP's are used with oil based fluid then at 80m/min cutting speed, high tool life (44.89 min) and low tool wear and surface roughness (0.497µm). Nanofluids nano particles contain oils with themselves and they release them in the machining zone and hence better lubrication is done by Nanofluids.

— Smaller the conc. of particles in the base fluids better the surface finish obtained as chances of clogging of particles reduces in small concentration and in MWCNT, SWCNT and CNT, the MWCNT is the best nanoparticles with various basefluid

— While we are using TiO2 with Karanja (bio) oil gives the peak tool temperatures reduced by 52% as compared to dry, i.e., 220–105℃ and an increase in surface finish quality of the average roughness by of about 50.7%. Highest heat transfer rate is obtained with bio oil cooling method rather than by spray impingement or only with water. Increase in the spindle speed, air pressure caused reduction in average surface roughness, but as either feed or depth of cut increased average surface roughness also increased.

— Carbon NP with dispersant (5 gm in 1000ml) used then Carbon NMQL conditions can provide excellent lubrication and cooling, which lead to high surface quality, small grinding forces and minor subsurface damage as compared to the dry, flood and MQL grinding conditions.

— When Graphite (0.15, 0.25, and 0.35vol% and 32nm diameter size) is used with Distilled water plus 20 vol. % canola oil then 0.35 vol. % graphite nanofluid MQL results in surface roughness reduction of 48.77% along and 43.55% in the grinding direction.

IV. FUTURE SCOPE

By the use of cooling fluid/nanofluid in machining, wok piece get good surface finish due to various property enhancement like high thermal conductivity, good lubricating property and rheological properties of nanofluid. But the properties can be enhanced by changing various parameters like NP's size, shape, concentration, flow rate, spray nozzle angle and distance of spraying. The disadvantages of using nanofluids are that it gives negative impact to environment and worker's health and cost is also high. So, scope is there for researchers to develop new type/modified nanofluid which are eco-friendly and less costly. Another promising area is to make/test the combination of different types of nanoparticles (hybrid nanoparticles) in order to enhance the results regarding metal removal rate, surface finish, thermal conductivity and various other properties.

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REFERENCES

[1]. Abbas, Adel Taha, Munish Kumar Gupta, Mahmoud S. Soliman, Mozammel Mia, Hussein Hegab, Monis Luqman, and Danil Yurievich Pimenov. (2019). "Sustainability Assessment Associated with Surface Roughness and Power Consumption Characteristics in Nanofluid MQL-Assisted Turning of AISI 1045 Steel." *International Journal of Advanced Manufacturing Technology,* 105(1–4):1311–27.

[2]. Alade, Ibrahim O., Tajudeen A. Oyehan, Idris K. Popoola, Sunday O. Olatunji, and Aliyu Bagudu (2018). "Modeling Thermal Conductivity Enhancement of Metal and Metallic Oxide Nanofluids Using Support Vector Regression." *Advanced Powder Technology, 29*(1):157–67.

[3]. Ali, M. A. M., A. N. M. Khalil, and Azwan Iskandar Azmi. (2015). "Effect of Minimum Quantity Lubricant of Al_2O_3 Nanoparticle with SDBS on Surface Roughness during Turning of Mild Steel." *Advanced Materials Research*

1119:75–79.
[4]. Anuj Kumar Sharma, Arun Kumar Tiwari, Amit Rai Dixit (2016). "Rheological Behavior of Nanofluids: A Review." *RENEWABLE AND SUBSTAINABLE ENERGY REVIEWS*.
[5]. Babita, S. K. Sharma, and Shipra Mital Gupta (2016). Preparation and Evaluation of Stable Nanofluids for Heat Transfer Application: A Review." *Experimental Thermal and Fluid Science, 79*: 202–212.
[6]. Behera, Bikash Chandra, Chetan, Dinesh Setti, Sudarsan Ghosh, and P. Venkateswara Rao (2017). "Spreadability Studies of Metal Working Fluids on Tool Surface and Its Impact on Minimum Amount Cooling and Lubrication Turning." *Journal of Materials Processing Technology, 244*: 1–16.
[7]. Cao, Yi. (2018). The Toxicity of Nanoparticles to Human Endothelial Cells." *Advances in Experimental Medicine and Biology, 1048*: 59–69.
[8]. Chai, Yee Ho, Suzana Yusup, Vui Soon Chok, Mohamad Taufiq Arpin, and Sonny Irawan (2016). "Investigation of Thermal Conductivity of Multi Walled Carbon Nanotube Dispersed in Hydrogenated Oil Based Drilling Fluids." *Applied Thermal Engineering, 107*:1019–25.
[9]. Chamsa-ard, Wisut, Sridevi Brundavanam, Chun Che Fung, Derek Fawcett, and Gerrard Poinern (2017). *Nanofluid Types, Their Synthesis, Properties and Incorporation in Direct Solar Thermal Collectors: A Review*.
[10]. Chatha, Sukhpal Singh, Amrit Pal, and Tarjeet Singh (2016). "Performance Evaluation of Aluminium 6063 Drilling under the Influence of Nanofluid Minimum Quantity Lubrication." *Journal of Cleaner Production, 137*: 537–545.
[11]. Chon, Chan Hee, Kenneth D. Kihm, Shin Pyo Lee, and Stephen U. S. Choi (2005). "Empirical Correlation Finding the Role of Temperature and Particle Size for Nanofluid (Al 2O 3) Thermal Conductivity Enhancement." *Applied Physics Letters*, *87*(15):1–3.
[12]. Das, Sarit Kumar, Nandy Putra, Peter Thiesen, and Wilfried Roetzel (2003). "Temperature Dependence of Thermal Conductivity Enhancement for Nanofluids." *Journal of Heat Transfer, 125*(4): 567–574.
[13]. Dhinesh Kumar, D., and A. Valan Arasu (2018). "A Comprehensive Review of Preparation, Characterization, Properties and Stability of Hybrid Nanofluids." *Renewable and Sustainable Energy Reviews, 81*, 1669–1689.
[14]. Garg, Akhil, Shrutidhara Sarma, B. N. Panda, Jian Zhang, and L. Gao. (2016). "Study of Effect of Nanofluid Concentration on Response Characteristics of Machining Process for Cleaner Production." *Journal of Cleaner Production, 135*: 476–89.
[15]. Gupta, Munish Kumar, Mozammel Mia, Catalin Iulian Pruncu, Aqib Mashood Khan, M. Azizur Rahman, Muhammad Jamil, and Vishal S. Sharma (2020). "Modeling and Performance Evaluation of Al2O3, MoS2 and Graphite Nanoparticle-Assisted MQL in Turning Titanium Alloy: An Intelligent Approach." *Journal of the Brazilian Society of Mechanical Sciences and Engineering, 42*(4): 1–21.
[16]. Gupta, Munish Kumar, P. K. Sood, and Vishal S. Sharma. (2016). "Optimization of Machining Parameters and Cutting Fluids during Nano-Fluid Based Minimum Quantity Lubrication Turning of Titanium Alloy by Using Evolutionary Techniques." *Journal of Cleaner Production, 135*: 1276–88.
[17]. Haddad, Zoubida, Chérifa Abid, Hakan F. Oztop, and Amina Mataoui (2014). "A Review on How the Researchers Prepare Their Nanofluids." *International Journal of Thermal Sciences, 76:* 168–89.
[18]. Huang, Wei Tai, Der Ho Wu, and Jian Ting Chen (2016). "Robust Design of Using Nanofluid/MQL in Micro-Drilling." *International Journal of Advanced Manufacturing Technology, 85*(9–12): 2155–2161.
[19]. Hwang, Y., H. S. Park, J. K. Lee, and W. H. Jung (2006). "Thermal Conductivity and Lubrication Characteristics of Nanofluids." *Current Applied Physics* 6(SUPPL. 1).
[20]. Jana, Soumen, Amin Salehi-Khojin, and Wei Hong Zhong (2007). "Enhancement of Fluid Thermal Conductivity by the Addition of Single and Hybrid Nano-Additives." *Thermochimica Acta, 462*(1–2): 45–55.
[21]. Jia, Dongzhou, Changhe Li, Dongkun Zhang, Yanbin Zhang, and Xiaowei Zhang (2014). "Experimental Verification of Nanoparticle Jet Minimum Quantity Lubrication Effectiveness in Grinding." *Journal of Nanoparticle Research.*
[22]. Kalita, Parash, Ajay P. Malshe, Wenping Jiang, and Albert J. Shih (2010). "Tribological Study of Nano Lubricant Integrated Soybean Oil for Minimum Quantity Lubrication (MQL) Grinding." *Transactions of the North American Manufacturing Research Institution of SME,* 38:137–44.
[23]. Kalita, Parash, Ajay P. Malshe, and Kamlakar P. Rajurkar (2012). "Study of Tribo-Chemical Lubricant Film Formation during Application of Nanolubricants in Minimum Quantity Lubrication (MQL) Grinding." *CIRP Annals - Manufacturing Technology,* 61(1):327–30.
[24]. Khanafer, K., A. Eltaggaz, I. Deiab, H. Agarwal, and A. Abdul-latif (2020). "Toward Sustainable Micro-Drilling of Inconel 718 Superalloy Using MQL-Nanofluid." *International Journal of Advanced Manufacturing Technology*.
[25]. Khandekar, S., M. Ravi Sankar, V. Agnihotri, and J. Ramkumar (2012). "Nano-Cutting Fluid for Enhancement of Metal Cutting Performance." *Materials and Manufacturing Processes, 27*(9): 963–967.
[26]. Kumar, M. Pradeep, V. Krishna Kanth, A. Ramki, and K. E. Jagadish (2019). *Experimental Investigation of Active Flux Coatings on AA-6082 Using A-TIG Welding Process BT - Recent Advances in Material Sciences*. Springer Singapore.
[27]. Kumar, Nishant, Shriram S. Sonawane, and Shirish H. Sonawane (2018). "Experimental Study of Thermal Conductivity, Heat Transfer and Friction Factor of Al_2O_3 Based Nanofluid." *International Communications in Heat and Mass Transfer, 90*: 1–10.
[28]. Kumar, Ramanuj, Ashok Kumar Sahoo, Purna Chandra Mishra, and Rabin Kumar Das (2020). "Influence of Al_2O_3 and TiO_2 Nanofluid on Hard Turning Performance." *International Journal of Advanced Manufacturing Technology, 106*(5–6): 2265–2280.
[29]. Lee, Ji Hwan, Kyo Sik Hwang, Seok Pil Jang, Byeong Ho Lee, Jun Ho Kim, Stephen U. S. Choi, and Chul Jin Choi (2008). "Effective Viscosities and Thermal Conductivities of Aqueous Nanofluids Containing Low Volume Concentrations of Al_2O_3 Nanoparticles." *International Journal of Heat and Mass Transfer, 51*(11–12): 2651–2656.
[30]. Lee, Pil Ho, Jung Soo Nam, Chengjun Li, and Sang Won Lee (2012). "An Experimental Study on Micro-Grinding Process with Nanofluid Minimum Quantity Lubrication (MQL)." *International Journal of Precision Engineering and Manufacturing, 13*(3):331–338.
[31]. Li, Haoran, Li Wang, Yurong He, Yanwei Hu, Jiaqi Zhu, and Baocheng Jiang (2014). "Experimental Investigation of Thermal Conductivity and Viscosity of Ethylene Glycol Based ZnO Nanofluids." *Applied Thermal Engineering, 88*: 363–368.
[32]. Liu, Min Sheng, Mark Ching Cheng Lin, C. Y. Tsai, and Chi Chuan Wang (2006). "Enhancement of Thermal Conductivity with Cu for Nanofluids Using Chemical Reduction Method." *International Journal of Heat and Mass Transfer* 49(17–18): 3028–3033.
[33]. Mahboob Ali, Mohd Asyraf, Azwan Iskandar Azmi,

Ahmad Nabil Mohd Khalil, and Kean Wei Leong (2017). “Experimental Study on Minimal Nanolubrication with Surfactant in the Turning of Titanium Alloys.” *International Journal of Advanced Manufacturing Technology, 92*(1–4): 117–127.
[34]. ManojKumar, K., and Amitava Ghosh (2015). “Synthesis of MWCNT Nanofluid and Evaluation of Its Potential besides Soluble Oil as Micro Cooling-Lubrication Medium in SQL Grinding.” *International Journal of Advanced Manufacturing Technology, 77*(9–12): 1955–1964.
[35]. Mao, Cong, Yong Huang, Xin Zhou, Hangyu Gan, Jian Zhang, and Zhixiong Zhou (2014). “The Tribological Properties of Nanofluid Used in Minimum Quantity Lubrication Grinding.” *International Journal of Advanced Manufacturing Technology, 71*(5–8): 1221–28.
[36]. Mao, Cong, Xiaojun Tang, Hongfu Zou, Xiangming Huang, and Zhixiong Zhou (2012). “Investigation of Grinding Characteristic Using Nanofluid Minimum Quantity Lubrication.” *International Journal of Precision Engineering and Manufacturing, 13*(10): 1745–1752.
[37]. Mao, Cong, Jian Zhang, Yong Huang, Hongfu Zou, Xiangming Huang, and Zhixiong Zhou (2013). “Investigation on the Effect of Nanofluid Parameters on MQL Grinding.” *Materials and Manufacturing Processes, 28*(4):436–442.
[38]. Mao, Cong, Hongfu Zou, Xiangming Huang, Jian Zhang, and Zhixiong Zhou (2013). “The Influence of Spraying Parameters on Grinding Performance for Nanofluid Minimum Quantity Lubrication.” *International Journal of Advanced Manufacturing Technology, 64*(9–12): 1791–1799.
[39]. Mao, Cong, Hongfu Zou, Xin Zhou, Yong Huang, Hangyu Gan, and Zhixiong Zhou (2014). “Analysis of Suspension Stability for Nanofluid Applied in Minimum Quantity Lubricant Grinding.” *International Journal of Advanced Manufacturing Technology, 71*(9–12): 2073–2081.
[40]. Masuda, Hidetoshi, Akira Ebata, Kazunari Teramae, and Nobuo Hishinuma (1993). “Alteration of Thermal Conductivity and Viscosity of Liquid by Dispersing Ultra-Fine Particles. Dispersion of Al_2O_3, SiO_2 and TiO_2 Ultra-Fine Particles.” *Netsu Bussei, 7*(4): 227–233.
[41]. Mintsa, Honorine Angue, Gilles Roy, Cong Tam Nguyen, and Dominique Doucet (2009). “New Temperature Dependent Thermal Conductivity Data for Water-Based Nanofluids.” *International Journal of Thermal Sciences, 48*(2): 363–371.
[42]. Murshed, S. M. S., K. C. Leong, and C. Yang (2005). “Enhanced Thermal Conductivity of TiO_2 - Water Based Nanofluids.” *International Journal of Thermal Sciences, 44*(4): 367–373.
[43]. Muthusamy, Y., K. Kadirgama, M. M. Rahman, D. Ramasamy, and K. V. Sharma (2016). “Wear Analysis When Machining AISI 304 with Ethylene Glycol/TIO_2 Nanoparticle-Based Coolant.” *International Journal of Advanced Manufacturing Technology, 82*(1–4): 327–340.
[44]. Najiha, M. S., and M. M. Rahman (2016). “Experimental Investigation of Flank Wear in End Milling of Aluminum Alloy with Water-Based TiO_2 Nanofluid Lubricant in Minimum Quantity Lubrication Technique.” *International Journal of Advanced Manufacturing Technology, 86*(9–12): 2527–2537.
[45]. Najiha, M. S., M. M. Rahman, and A. R. Yusoff (2015). “Flank Wear Characterization in Aluminum Alloy (6061 T6) with Nanofluid Minimum Quantity Lubrication Environment Using an Uncoated Carbide Tool.” *Journal of Manufacturing Science and Engineering, Transactions of the ASME.*
[46]. Nam, Jung Soo, Pil Ho Lee, and Sang Won Lee (2011a). “Experimental Characterization of Micro-Drilling Process Using Nanofluid Minimum Quantity Lubrication.” *International Journal of Machine Tools and Manufacture, 51*(7–8): 649–652.
[47]. Nam, Jung Soo, Pil Ho Lee, and Sang Won Lee (2011b). “Experimental Characterization of Micro-Drilling Process Using Nanofluid Minimum Quantity Lubrication.” *International Journal of Machine Tools and Manufacture, 51*(7–8): 649–652.
[48]. Pang, Changwei, Jung Yeul Jung, Jae Won Lee, and Yong Tae Kang (2012). “Thermal Conductivity Measurement of Methanol-Based Nanofluids with Al_2O_3 and SiO_2 Nanoparticles.” *International Journal of Heat and Mass Transfer, 55*(21–22): 5597–5602.
[49]. Paswan, Kamlesh, A. Pramanik, and S. Chattopadhyaya (2020). “Machining Performance of Inconel 718 Using Graphene Nanofluid in EDM.” *Materials and Manufacturing Processes, 35*(1), 33–42.
[50]. Patel, Hrishikesh E., Sarit K. Das, T. Sundararajan, A. Sreekumaran Nair, Beena George, and T. Pradeep (2003). “Thermal Conductivities of Naked and Monolayer Protected Metal Nanoparticle Based Nanofluids: Manifestation of Anomalous Enhancement and Chemical Effects.” *Applied Physics Letters, 83*(14): 2931–2933.
[51]. Prabhu, S., and B. K. Vinayagam (2010). “Nano Surface Generation of Grinding Process Using Carbon Nano Tubes.” *Sadhana - Academy Proceedings in Engineering Sciences, 35*(6): 747–60.
[52]. Prabhu, S., and B. K. Vinayagam (2011). “Fractal Dimensional Surface Analysis of AISI D2 Tool Steel Material with Nanofluids in Grinding Process Using Atomic Force Microscopy.” *Journal of the Brazilian Society of Mechanical Sciences and Engineering, 33*(4):459–664.
[53]. Prabhu, S., and B. K. Vinayagam (2013). “Analysis of Surface Characteristics by Electrolytic In-Process Dressing (ELID) Technique for Grinding Process Using Single Wall Carbon Nano Tube-Based Nanofluids.” *Arabian Journal for Science and Engineering, 38*(5): 1169–1178.
[54]. Prabhu, Sethuramalingam, and Babu Kuppusamy Vinayagam (2012). “AFM Investigation in Grinding Process with Nanofluids Using Taguchi Analysis.” *International Journal of Advanced Manufacturing Technology, 60*(1–4): 149–160.
[55]. Prasad, A. Renuka, Sumer Singh, and Harish Nagar (2017). “A Review on Nanofluids: Properties and Applications.” *International Journal Of Advance Research And Innovative Ideas In Education, 3*(3): 3185–3209.
[56]. Pryazhnikov, M. I., A. V. Minakov, V. Ya Rudyak, and D. V. Guzei (2017). “Thermal Conductivity Measurements of Nanofluids.” *International Journal of Heat and Mass Transfer, 104*: 1275–1282.
[57]. Qu, Shuoshuo, Yadong Gong, Yuying Yang, Wenwen Wang, Chunyou Liang, and Bing Han (2020). “An Investigation of Carbon Nanofluid Minimum Quantity Lubrication for Grinding Unidirectional Carbon Fibre-Reinforced Ceramic Matrix Composites.” *Journal of Cleaner Production.*
[58]. Rahmati, Bizhan, Ahmed A. D. Sarhan, and M. Sayuti (2014). “Investigating the Optimum Molybdenum Disulfide (MoS_2) Nanolubrication Parameters in CNC Milling of AL6061-T6 Alloy.” *International Journal of Advanced Manufacturing Technology, 70*(5–8): 1143–1155.
[59]. Rahmati, Bizhan, Ahmed A. D. Sarhan, and M. Sayuti (2014). “Morphology of Surface Generated by End Milling AL6061-T6 Using Molybdenum Disulfide (MoS_2) Nanolubrication in End Milling Machining.” *Journal of Cleaner Production, 66*: 685–691.
[60]. Raju, Roja Abraham, Atul Andhare, and Neelesh Kumar Sahu (2017). “Performance of Multi-Walled Carbon Nanotube-Based Nanofluid in Turning Operation.” *Materials*

and Manufacturing Processes, 32(13): 1490–96.
[61]. Rostamian, Seyed Hadi, Mojtaba Biglari, Seyfolah Saedodin, and Mohammad Hemmat Esfe (2017). "An Inspection of Thermal Conductivity of CuO-SWCNTs Hybrid Nanofluid versus Temperature and Concentration Using Experimental Data, ANN Modeling and New Correlation." *Journal of Molecular Liquids,* 231: 364–369.
[62]. Roy, Soumikh, Ramanuj Kumar, Ashok Kumar Sahoo, and Rabin Kumar Das (2019). "A Brief Review on Effects of Conventional and Nano Particle Based Machining Fluid on Machining Performance of Minimum Quantity Lubrication Machining." *Materials Today: Proceedings, 18*: 5421–5431.
[63]. Sahooli, M., S. Sabbaghi, and M. Shariaty Niassar (2012). "Preparation of CuO/Water Nanofluids Using Polyvinylpyrolidone and a Survey on Its Stability and Thermal Conductivity." *International Journal of Nanoscience and Nanotechnology, 8*(1): 27–34.
[64]. Salimi-Yasar, Hamid, Saeed Zeinali Heris, Mehdi Shanbedi, Ahmad Amiri, and Ali Kameli (2017). "Experimental Investigation of Thermal Properties of Cutting Fluid Using Soluble Oil-Based TiO_2 Nanofluid." *Powder Technology, 310*: 213–220.
[65]. Samuel, J., J. Rafiee, P. Dhiman, Z. Z. Yu, and N. Koratkar (2011). "Graphene Colloidal Suspensions as High Performance Semi-Synthetic Metal-Working Fluids." *Journal of Physical Chemistry C 115*(8): 3410–3415.
[66]. Saravanakumar, N., L. Prabu, M. Karthik, and A. Rajamanickam (2014). "Experimental Analysis on Cutting Fluid Dispersed with Silver Nano Particles." *Journal of Mechanical Science and Technology, 28*(2): 645–651.
[67]. Sayes, Christie M., Feng Liang, Jared L. Hudson, Joe Mendez, Wenhua Guo, Jonathan M. Beach, Valerie C. Moore, Condell D. Doyle, Jennifer L. West, W. Edward Billups, Kevin D. Ausman, and Vicki L. Colvin (2006). "Functionalization Density Dependence of Single-Walled Carbon Nanotubes Cytotoxicity in Vitro." *Toxicology Letters, 161*(2): 135–142.
[68]. Sayuti, M., Ahmed A. D. Sarhan, and M. Hamdi (2013). "An Investigation of Optimum SiO_2 Nanolubrication Parameters in End Milling of Aerospace Al6061-T6 Alloy." *International Journal of Advanced Manufacturing Technology, 67*(1–4): 833–849.
[69]. Sayuti, M., Ahmed A. D. Sarhan, Tomohisa Tanaka, M. Hamdi, and Yoshio Saito (2013). "Cutting Force Reduction and Surface Quality Improvement in Machining of Aerospace Duralumin AL-2017-T4 Using Carbon Onion Nanolubrication System." *International Journal of Advanced Manufacturing Technology, 65*(9–12): 1493–1500.
[70]. Sayuti, Mohd, Ooi Ming Erh, Ahmed A. D. Sarhan, and Mohd Hamdi (2014). "Investigation on the Morphology of the Machined Surface in End Milling of Aerospace AL6061-T6 for Novel Uses of SiO_2 Nanolubrication System." *Journal of Cleaner Production, 66*: 655–663.
[71]. Sayuti, Mohd, Ahmed A. D. Sarhan, and Faheem Salem (2014). "Novel Uses of SiO2 Nano-Lubrication System in Hard Turning Process of Hardened Steel AISI4140 for Less Tool Wear, Surface Roughness and Oil Consumption." *Journal of Cleaner Production,* 67: 265–76.
[72]. Sen, Binayak, Mozammel Mia, Munish Kumar Gupta, M. Azizur Rahman, Uttam Kumar Mandal, and Sankar Prasad Mondal (2019). "Influence of Al_2O_3 and Palm Oil–Mixed Nano-Fluid on Machining Performances of Inconel-690: IF-THEN Rules–Based FIS Model in Eco-Benign Milling." *International Journal of Advanced Manufacturing Technology, 103*(9–12): 3389–3403.
[73]. Sen, Binayak, Mozammel Mia, G. M. Krolczyk, Uttam Kumar Mandal, and Sankar Prasad Mondal (2019). *Eco-Friendly Cutting Fluids in Minimum Quantity Lubrication Assisted Machining: A Review on the Perception of Sustainable Manufacturing*. Korean Society for Precision Engineering.
[74]. Setti, Dinesh, Manoj Kumar Sinha, Sudarsan Ghosh, and P. Venkateswara Rao (2015). "Performance Evaluation of Ti-6Al-4V Grinding Using Chip Formation and Coefficient of Friction under the Influence of Nanofluids." *International Journal of Machine Tools and Manufacture, 88*: 237–248.
[75]. Seyedzavvar, Mirsadegh, Mohammadreza Shabgard, and Mousa Mohammadpourfard (2019). "Investigation into the Performance of Eco-Friendly Graphite Nanofluid as Lubricant in MQL Grinding." *Machining Science and Technology, 23*(4): 569–594.
[76]. Shabgard, Mohammadreza, Mirsadegh Seyedzavvar, and Mousa Mohammadpourfard (2017). "Experimental Investigation into Lubrication Properties and Mechanism of Vegetable-Based CuO Nanofluid in MQL Grinding." *International Journal of Advanced Manufacturing Technology, 92*(9–12): 3807–3823.
[77]. Sharma, Anuj Kumar, Rabesh Kumar Singh, Amit Rai Dixit, and Arun Kumar Tiwari (2017). "Novel Uses of Alumina-MoS_2 Hybrid Nanoparticle Enriched Cutting Fluid in Hard Turning of AISI 304 Steel." *Journal of Manufacturing Processes, 30*: 467–482.
[78]. Sharma, Anuj Kumar, Arun Kumar Tiwari, and Amit Rai Dixit (2016). "Characterization of TiO_2, Al_2O_3 and SiO_2 Nanoparticle Based Cutting Fluids." *Materials Today: Proceedings, 3*(6):1890–1898.
[79]. Sharma, Pankaj, Il Hyun Baek, Taehyun Cho, Sangdo Park, and Ki Bong Lee (2011). "Enhancement of Thermal Conductivity of Ethylene Glycol Based Silver Nanofluids." *Powder Technology, 208*(1): 7–19.
[80]. Shen, Bin, Parash Kalita, Ajay P. Malshe, and Albert J. Shih (2008). "Performance of Novel MoS2 Nanoparticles Based Grinding Fluids in Minimum Quantity Lubrication Grinding." *Transactions of the North American Manufacturing Research Institution of SME, 36*: 357–364.
[81]. Shen, Bin, Albert J. Shih, and Simon C. Tung (2008). "Application of Nanofluids in Minimum Quantity Lubrication Grinding." *Tribology Transactions, 51*(6): 730–737.
[82]. Shen, Bin, Albert J. Shih, and Simon C. Tung (2009). "Peer-Reviewed: Application of Nanofluids in Minimum Quantity Lubrication Grinding." *Tribology and Lubrication Technology, 65*(3): 73–80.
[83]. Sidik, Nor Azwadi Che, Syahrullail Samion, Javad Ghaderian, and Muhammad Noor Afiq Witri Muhammad Yazid (2017). "Recent Progress on the Application of Nanofluids in Minimum Quantity Lubrication Machining: A Review." *International Journal of Heat and Mass Transfer, 108*: 79–89.
[84]. Singh, Rabesh Kumar, Amit Rai Dixit, Amitava Mandal, and Anuj Kumar Sharma (2017). "Emerging Application of Nanoparticle-Enriched Cutting Fluid in Metal Removal Processes: A Review." *Journal of the Brazilian Society of Mechanical Sciences and Engineering, 39*(11): 4677–4717.
[85]. Sinha, Kaustav, Barkan Kavlicoglu, Yanming Liu, Faramarz Gordaninejad, and Olivia A. Graeve (2009). "A Comparative Study of Thermal Behavior of Iron and Copper Nanofluids." *Journal of Applied Physics.*
[86]. Sinha, Manoj Kumar, Rajeshkumar Madarkar, Sudarsan Ghosh, and P. Venkateswara Rao (2017). "Application of Eco-Friendly Nanofluids during Grinding of Inconel 718 through Small Quantity Lubrication." *Journal of Cleaner Production, 141*: 1359–1375.
[87]. Srihari, N. Balaji Ganesh and P. V. (2019). *Methodologies to Optimize Engine*. Springer Singapore.
[88]. Srikant, R. R., D. N. Rao, M. S. Subrahmanyam, and P. Vamsi Krishna (2009). "Applicability of Cutting Fluids with Nanoparticle Inclusion as Coolants in Machining."

Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 223(2): 221–225.
[89]. Su, Yu, Le Gong, Bi Li, Zhiqiang Liu, and Dandan Chen (2016). "Performance Evaluation of Nanofluid MQL with Vegetable-Based Oil and Ester Oil as Base Fluids in Turning." *International Journal of Advanced Manufacturing Technology, 83*(9–12): 2083–2089.
[90]. Vamsi Krishna, P., R. R. Srikant, and D. Nageswara Rao (2010). "Experimental Investigation on the Performance of Nanoboric Acid Suspensions in SAE-40 and Coconut Oil during Turning of AISI 1040 Steel." *International Journal of Machine Tools and Manufacture, 50*(10): 911–916.
[91]. Vamsi Krishna, P., R. R. Srikant, R. Padmini, and Bharat Parakh (2012). "Basic Properties and Performance of Vegetable Oil-Based Boric Acid Nanofluids in Machining." *Emerg. Trends Sci. Eng. Technol. Lect. Notes Mech. Eng.,* 197–206.
[92]. Wang, Yaogang, Changhe Li, Yanbin Zhang, Min Yang, Xianpeng Zhang, Naiqing Zhang, and Jingjie Dai. (2017). "Experimental Evaluation on Tribological Performance of the Wheel/Workpiece Interface in Minimum Quantity Lubrication Grinding with Different Concentrations of Al2O3 Nanofluids." *Journal of Cleaner Production, 142*: 3571–83.
[93]. Wickramasinghe, K. C., Hiroyuki Sasahara, Erween Abd Rahim, and G. I. P. Perera (2020). "Green Metalworking Fluids for Sustainable Machining Applications: A Review." *Journal of Cleaner Production.*
[94]. X. Wang, X. Xu, and S. U. Choi (1999). "Thermal Conductivity of Nano-Particles-Fluid Mixture." *Journal of Thermophysics and Heat Transfer.*
[95]. Yan, Jiwang, Zhiyu Zhang, and Tsunemoto Kuriyagawa (2011). "Effect of Nanoparticle Lubrication in Diamond Turning of Reaction-Bonded SiC." *International Journal of Automation Technology, 5*(3): 307–312.
[96]. Yiamsawasd, Thakleaw, Ahmet Selim Dalkilic, and Somchai Wongwises (2012). "Measurement of the Thermal Conductivity of Titania and Alumina Nanofluids." *Thermochimica Acta, 545*: 48–56.
[97]. Yıldırım, Çağrı Vakkas, Murat Sarıkaya, Turgay Kıvak, and Şenol Şirin (2019). "The Effect of Addition of HBN Nanoparticles to Nanofluid-MQL on Tool Wear Patterns, Tool Life, Roughness and Temperature in Turning of Ni-Based Inconel 625." *Tribology International, 134,* 443–456.
[98]. Zhang, Dongkun, Changhe Li, Dongzhou Jia, Yanbin Zhang, and Xiaowei Zhang (2015). "Specific Grinding Energy and Surface Roughness of Nanoparticle Jet Minimum Quantity Lubrication in Grinding." *Chinese Journal of Aeronautics, 28*(2): 570–581.
[99]. Zhang, Xing, Hua Gu, and Motoo Fujii (2007). "Effective Thermal Conductivity and Thermal Diffusivity of Nanofluids Containing Spherical and Cylindrical Nanoparticles." *Experimental Thermal and Fluid Science, 31*(6): 593–599.
[100]. Zhang, Yanbin, Changhe Li, Dongzhou Jia, Benkai Li, Yaogang Wang, Min Yang, Yali Hou, and Xiaowei Zhang (2016). Experimental Study on the Effect of Nanoparticle Concentration on the Lubricating Property of Nanofluids for MQL Grinding of Ni-Based Alloy." *Journal of Materials Processing Technology, 232*: 100–115.
[101]. Zhang, Yanbin, Changhe Li, Dongzhou Jia, Dongkun Zhang, and Xiaowei Zhang (2015). "Experimental Evaluation of MoS_2 Nanoparticles in Jet MQL Grinding with Different Types of Vegetable Oil as Base Oil." *Journal of Cleaner Production, 87*(C): 930–940.

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