Effect of Cutting Fluids in Machining: A Review

Deepak Kumar Sharma*, Krishna Murari Pandey

Dept. of Mechanical Engineering, NIT Silchar, Assam, India, 788010

*Corresponding author's e-mail: deepakseti.sharma69@gmail.com

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ABSTRACT

In the machining operations, the cutting zone needs lubrication and cooling, that are supplied by cutting fluids. In the machining domain's route to long-term sustainability in turning, milling, or drilling, nanofluid applied as a metalworking fluid, provides notable outcomes compared to traditional cutting fluids. Due to its efficient thermo-physical qualities, nanofluid emerged as highly capable of working as a good cutting fluid. This review provides in-depth information about the impact of various cutting fluids based on mineral oil, vegetable oil, nanofluids, hybrid nanofluids, and machining with dry and air cooling. The primary aim of all machining processes is to reduce production costs by raising productivity and quality. The thermophysical properties, methodologies of preparing hybrid nanofluid, synthesis, and characterization are briefly presented. Based on many literature reviews, it is found that the nano-cutting fluid reduces the temperature of tools, tool wear, and surface quality while also being less hazardous to the environment. The application and effect of various nano-cutting fluids, and hybrid fluids in flood cooling and dry machining are discussed and also compared in this comprehensive review. This study concentrated on reviewing the experimental and numerical observations obtained by applying the various types of cutting fluids during the cutting process by many authors. The different cutting parameters are compared in mono-type nanofluids and hybrid nanofluids for turning and milling operations. The utilization of hybrid nanofluid in different cutting operations resulted in one of the essential sustainable developments.

Keywords: Machining; Thermo-physical properties; Nanoparticles; Minimum quantity lubrication

1 Introduction

Cutting fluids (CFs) cool the surface of the workpiece and cutting tool, lubricate the interface of the tool and the workpiece, and remove fragments from the machining area during the machining process. CFs cool and lubricate to reduce cutting area heat and friction wear. These fluids have also reduced friction through lubrication. The tribological properties of the machining are also affected during the time of tool and workpiece make contact. Nowadays, machining has a great impact on manufacturing industries. Many developments are ongoing to improve good sound quality and highly profitable products at minimum costs in machining. The known parameters of machining, which enhance the production rate also detrimentally affect the product quality and tool life [1], [2]. Mineral oil-based fluids for cutting are prepared using petroleum-based products and mixed with some additives like sulfur oils, phosphorus compounds, free sulfur, and fatty acids. These additives react with tool material during machining and thus hamper the surface integrity and mechanical properties of the workpiece. However, the trend for using vegetable-based cutting fluid (VBCFs) has increased recently. These fluids are eco-friendly and beneficial to machining industries and also, they are very regenerative, biodegradable, less harmful, and can be disposed of quickly [3], [4]. As per a review by Irani *et al.* [5] cutting fluids are classified into four categories as per their chemical composition: soluble oil, synthetics, semi-synthetics, and straight oil. Nanoparticles in the base fluid are suspended colloidal, producing nano-cutting fluid, a newly discovered cutting fluid (CF). Yan *et al.* [6] reviewed CF's impact on the machined surface quality and performance. Cooling is the most crucial effect in high-speed machining operations, mainly for water-based fluid. Cutting Fluid decreases the tool and

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workpiece temperature by transferring the temperature away from the cutting space. Cutting Fluid has been examined for its impact on cutting force, tool abrasion, chip deformation, the surface roughness of machined material, residual stress, and hardness. Using the Taguchi orthogonal array approach, Debnath *et al.* [7] investigated how various cutting fluids affect surface roughness and tool wear. The feed rate affects surface roughness by 34% while the flow rate of cutting fluids contributes 33.1%. Gupta *et al.* [8] have experimentally investigated numerous considerations like cutting forces, temperature, tool deterioration, and surface quality. The effects of cutting velocity, approach angle, and feed rate using adequate cutting fluids have also been studied. Karanja oil performance in water-cutting fluid in the straight-line cutting of AISI 1045 steel has been studied by Nizamuddin *et al.* [9]. It was observed that using water-based Karanja oil cutting fluid, the chip thickness is 11% thinner than with typical cutting fluids. As per various literature observations, it was found that most of the work has been done over mineral oils and vegetable oil-based cutting fluids, but less work was observed over cryogenic, dry, and air-cooling methods. The current review article concentrated on a specific type of cutting fluid and cutting fluid application procedures.

Nomenclature

CF	Cutting Fluid
MQL	Minimum Quantity Lubrication
MQCF	Minimum Quantity Cutting Fluid
VBCFs	Vegetable based cutting fluids
FEM	Finite Element Method
POME	Palm Oil Methyl Ester
VO	Vegetable Oil
MQCL	Minimum Quantity Cooling Lubrication
NCF	Nano Cutting Fluid
TTC	Tool Chip Contact Length
DPM	Discrete Phase Model
MWCNT	Multi-Walled Carbon Nanotube
Npi	Nanoparticle inclusions

2 Classifications of cutting fluids

2.1 Mineral oil-based cutting fluids

A raw material made of fossils is mineral oil. It originated from old woods millions of years ago when sediments buried the plant biomass. Willing *et al.* [10] focused on the ecological properties of synthetic (oleo chemical) esters. Physical-chemical characteristics of Oleo chemical esters can satisfy all technical specifications for creating high-performance lubricants and industrial oils. Esters contain good lubrication properties like high viscosity index, moderate volatility, exceptional shear stability, excellent lubrication qualities, and strong heat stability. This oil comes in the categories of Neat oil or Insoluble oil. Mineral oils are extensively used as CFs in machining industries because it is inexpensive. However, mineral oil contains poor biodegradability, creating long-term environmental pollution. Therefore, the interest in biodegradable fluid is continuously increasing with applications of vegetable oil-based cutting fluid as a replacement for inorganic oil cutting fluids and they are sustainable while mineral-based CFs have limited and constantly decreased [11].

Cutting fluids makes easy operations in machining, producing low surface roughness and an increased production rate. Gharaibeh [12] experimentally studied the surface condition of aluminium alloy (T6-6061) using different cutting fluids. As per result, lubricating oil was followed by mineral oil, which had the minimum (best) roughness coefficient at a 5% water ratio. The roughness coefficients of kerosene and natural oil were the greatest. One of the most prevalent cutting activities in the industry is milling. Because the milling process is interrupted, more incredible speeds may be used, increasing productivity. Cutting temperature is an important parameter to consider while optimizing a process. Cutting temperature analysis is more challenging in milling than in turning, owing to experimental challenges and transitory features. This paper describes a novel practical approach for measuring face milling temperatures, which is then utilized to validate the analytical model [13].

Duchosal *et al.* [14] have improved the minimal lubrication coolant constraints for surface finishing in the milling process at different cutting velocities. This environmentally friendly technology may be used for cleaner manufacturing in various situations. The spray direction is projected to improve due to the high orientation. Due to cutting speed and the spinning tool's aerodynamic impact, the inlet pressure must be made to emit an oily mist to the cutting area easily. The cutting speed must be sufficient, possibly in high-speed machining. However, a low feed rate in High-Speed Machining is preferable since it reduces cutting forces and temperature. Sukaylo *et al.* [15] have described the practical and theoretical effect of heat generation modelling and transmission processes in turning when applied to different cooling and lubrication fluids application techniques, including flood cooling application, MCQF, and dry machining. The thermally induced deformation and surface temperatures of the workpiece were calculated using the FEM technique with the ANSYS V5.5.3 software.

2.2 Vegetable oil-based cutting fluid

Because of the numerous disadvantages of straight cutting fluids and the desire to find an environmentally friendly cutting fluid, researchers are concentrating their efforts on developing efficient products and substitutes for traditional cutting fluids in the form of non-edible oils and VBCF that are commonly applied in the manufacturing industry nowadays. The performance of these alternatives was found more accurate than mineral oils because of their high level of natural lubricity, which improves the strength of intermolecular interactions on metal surfaces. Non-editable oils like Neem oil, Jatropha oil, Karanja oil, cottonseed oil, and Castor oil have better tribological properties than mineral oils. They become good environment-friendly [16].

Puttaswamy *et al.* [17] investigate the impact of VBCFs during the drilling of AISI304L stainless steel using the MQL technique. Neem oil and Mahua oil were used in this experiment because they contained the oleic acid (omega-9 fatty acid) 45% and 49%, respectively. This monounsaturated oleic acid has good stability and low thermal properties due to it increasing the lubrication properties of both VBCFs. Mahua oil showed less tool wear while Neem oil cutting fluid provides superior results in case of surface roughness and thrust force. To reduce the heat and tool wear, mineral oil cutting fluid has performed better and is more suitable as compared to Neem oil-based cutting fluid. Various observations of many researchers have been reviewed by Shashidhara *et al.* [18] found these contributions directed to applications of VBCFs. The research focused on the development of VBCFs for industries, mainly in the metal cutting and forming industries. Anand *et al.* [19] experimentally examined the Synergism effect of Graphene and TiO_2 as nano additives on machining and rheological properties of biodegradable vegetable oil (rice bran). This rheological investigation exhibited that increasing the nanoparticle concentration improved the viscosity of hybrid (Graphene/TiO_2 /rice bran oil) and mono (TiO_2 /rice bran oil) systems. The differences in viscosity with temperature were a crucial factor taken into account in this nanofluid investigation. Surface and tool wear properties were enhanced with the inclusion of TiO_2 into the base oil. The performance of a new cooling technique that is eco-friendly and user-friendly prepared by mixing vegetable oil in water has been investigated by Shokoohi *et al.* [20]. This technique is useful to reduce heat generation and power

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consumption in turning operations. As a result, a significant improvement in machining parameters like machining power, surface roughness, and chip formation was obtained in this study. This novel cooling technique may efficiently improve the productivity of machining operations as beneficial for operator health, microbial aspects, and environmental and economic effects. Agrawal *et al.* [21] examined the effect of non-edible green cutting fluid (mixture of cottonseed oil and aloe vera gel) in the cutting of M2 Steel. Different cutting fluids including aloe vera oil and traditional cutting fluids, were used in various machining settings with the Carbide cutting tool. The surface roughness of mineral oil and vegetable oil was obtained with the MQL technique and compared. By comparing to traditional cutting fluids, Surface roughness is reduced by 6.7%, and tool wear is decreased by 0.14% with aloe vera oil.

Sharma *et al.* [22] have reviewed the machinability that is affected by eco-friendly machining. Wear on the tools and surface abrasion are always regarded as indicators of product quality in finished or semi-finished goods. The major goal of this review article is to investigate several environmentally friendly machining methods and to promote the use of cooling in machining operations. Finally, it may be concluded that environmentally friendly machining is both cost-effective and environmentally beneficial.

In several machining operations, Sharma *et al.* [23] summarized some of the most relevant published research articles based on nanoparticle-enhanced cutting fluids. Furthermore, the influence of numerous kinds of nanofluids on the performance of different machining operations is discussed in this study. According to the literature reviews, the majority of experiments revealed that tribological characteristics improved as the nano molecules concentration increased in the base fluid, also the consumption of power, wear in the tool, cutting force, friction coefficient nodal, and temperature were lowered by using nanofluids. Katna *et al.* [24] have experimentally studied the presentation of biodegradable cutting fluid in machining operations. A fully biodegradable cutting fluid was prepared in this experiment, by taking non-edible neem oil as base oil. Because neem oil contains antibacterial qualities, it can prevent microbiological contamination for a long time. It is experimentally defined that the developed biodegradable cutting fluid is more efficient than mineral oil CF. Neem oil is also conveniently offered in large amounts for a lower price.

2.3 Cryogenic cooling

Cryogenic machining, with liquid nitrogen (LN_2) and CO_2 cooling medium, becomes a suitable alternative to the traditional flood cooling system of the machining process. Lu *et al.* [25] have developed a liquid nitrogen delivery, and cutting tool system to improve machining performance. Using cryogenic cooling could increase the performance of machining for cutting difficult materials. Tahmasebi *et al.* [26] used CFD to investigate the interaction of liquid nitrogen (LN_2) in the coolant transport system with the coolant jet to the cutting region. Also, the influence of operating circumstances, such as nozzle shape, cavitation development inside the cutting tool, pressure of coolant, and wall temperature, on coolant delivery efficiency has been investigated in this study.

Cryogenics CO_2 is another cryogenic used to substitute conventional oil emulsions. The CO_2 cooling technique is generally used as external cooling, so its improvement is needed. Pereira *et al.* [27] have applied CO_2 as a tool for internal coolant and optimized the result with external coolant during the milling of Inconel 718. The result showed that internal CO_2 cooling has more efficient the external CO_2 cooling from an environmental and economic point of view. A sustainable machining system is necessary in this era for that Jamil *et al.* [28] have done an experiment using MQL, Cryogenic LN_2, and CO_2 –Snow. The results revealed that CO_2 -snow increased life by reducing surface roughness by 47% of the cutting tool by 50% in comparison with dry cutting while Cryo LN_2 minimized the cutting temperature. Similarly turning operation of one of the hard-to-cut materials Titanium alloys Ti-6Al-4V has been processed by the combined application of MQL and cryogenic technique by Gajrani [29]. The result was compared with dry machining and found that Cry-MQL reduced machining force by 27% and surface roughness by 46%. Sharma *et al.* [30] reviewed MQL and cryogenically cooled machining methods as stepping stones in the quest for dry cutting. However, because machining is always fraught with challenges, none of these approaches has delivered a perfect answer. The outcomes were in direct rivalry with each other. MQL provides better results comparatively for grinding, milling, turning, and drilling for all materials.

2.4 Dry machining and Air cooling

In dry machining, there is no kind of cutting fluids are applied therefore it comes into the category of cleanest manufacturing. The tools, workpiece materials, and other machining process parameters are handled very carefully for successful operations [31]. Dry machining is popularly used due to some advantages compared to cutting fluids operations, no disposal of CFs benefits the environment and human health, and no filtration and cleaning costs reduce overall production costs. Despite this dry machining having some issues with CFs' unsustainable qualities, this method produces higher temperatures since there is generally more adhesion and friction between the cutting tool and the workpiece. Due to increased tool attrition, the result indicated a decrease in tool longevity, cutting tool overheating due to frictions, bad surface quality, and built-up edge formations [32]. High surface quality improves fatigue strength, creep behaviour, corrosion resistance, and surface friction. The finished machining class has a significant impact on milling processes. The effect of cutting fluid pressure and cutting variables on thread crest surface measurement during high-speed milling was investigated by Khorasani *et al.* [33]. The thread crest surface roughness was reduced by decreasing fluid pressure, feed rate, and spindle speed. According to the test results, raising the cutting velocity at a feed rate of 0.41 to 0.45 meters per minute and a cutting fluid pressure of 2.35 to 3.75 bars, improved cutting quality and surface quality.

Many experiments have been done by Rao G *et al.* [34] to control cutting parameters during the turning process, but it is difficult to limit these parameters directly in dry machining, thus various lubricants have been used to limit these parameters till today. Even though various investigations on the lubricity and thermal conductivity of nanofluids with MQL have been conducted in a range of domains. This work has carried out the preparation of nanofluid by mixing of nanoparticles Al_2O_3 to vegetable fluids with 6% and 8% by volume separately and then cutting nanofluid used in the milling of EN-36 steel.

A rising corpus of knowledge in sustainable manufacturing engineering is being created as a result of increased interest in processes' long-term viability. This research work is on an overview of ideas relevant to long-term machining processes by Chandel *et al.* [35] Sustainable manufacturing has arisen as a broad word that incorporates critical features in a variety of fields, including machining. High-performance cutting tool dry machining yields a long-lasting result.

Boswell and Chandratilleke [36] have examined the functioning effectiveness of a device that was used to cool the tool tip during machining operations with dry and air cooling methods namely the Ranque-Hilsch vortex tube. The result showed that the performance of air cooling is greatly enhanced by using the Ranque-Hilsch vortex tube, which supplies cold air to the tool's interface. This study demonstrated the outcomes obtained by combining compressed air with a vortex tube. It was found that the temperature during air-cooling was 60 °C, which is 210 °C colder than dry machining and 40 °C colder than the temperature attained during traditional wet machining. A comparative study was done by Sharma and Dixit [37] to find the effect of a ceramic tool with mixed oxide in air-cooled and grey cast iron spinning under dry conditions. A novel neural network training procedure is applied in this study. The study focused on the forces and vibration experienced during cutting, tool wear, and the machining job's surface roughness. Initially, the dry machining performed satisfactorily in the limited process variables. The analysis was expanded to include the tool life range where dry turning provided poor performance. Air cooling was found to dramatically minimize tool wear at high cutting rates while dry turning performed ineffectively while air-cooled turning provides a better surface finish. Along with experimental studies, some numerical analysis of the impact of air cooling in machining is also carried out. Perri *et al.* [38] looked at how cold air behaves thermally and fluidly. A simulation model was created to forecast the temperature field and the tool's displacements as a result of thermal influences. Results demonstrated that a wide range of cold air flow rates may be used to obtain nearly identical temperature conditions for the TCP. This indicates that decreasing the air flow rate to achieve the desired working temperature may result in energy savings.

3 Classifications of cutting fluid applications techniques

3.1 Minimum Quantity Lubrication (MQL)

Minimum Quantity Lubrication is used to substitute of flood cooling systems in machining by reducing its volume hugely. During the machining process, in order to cool and lubricate the interface between the workpiece and the cutting tool, conventional cooling is largely used. Flood cooling is health hazardous and also costly, so researchers developed a new technique, MQL, which is less harmful and economically beneficial. MQL is also often referred to as "near-dry machining". Very little lubricant is misted or atomized using the MQL process, typically at a flow rate of between 50 and 500 milliliters per hour. For getting good lubrication properties in the MQL technique, synthetic Easter oil or vegetable oil is used instead of mineral oil. In turning operation, cutting fluid based on mineral oil (MO) performs a vital function, although it is toxic to the environment and human health. MO was replaced with green cutting fluid (GCF), a minimal quantity cutting fluid (MQCF) application technique green cutting fluid with a vegetable base. GCF has been found with less corrosion with grade 3, whereas it varies between 8 and 9 in MO-based cutting fluid [39].

Boubekri *et al.* [40] reviewed the many research works based on the MQL technique and concluded that MQL has demonstrated good performance in short-term tests across a variety of procedures. However, Long term capability and robustness are still the work of research while the applications MQL have indicated a good cost reduction due to the reduction of supply of the CFs. Compared to flood cooling, MQL applications generate a significant volume of mist. To get the benefits of MQL, the latter must be well-regulated [41]. To control this fine mist, mist collecting or filtering equipment is usually necessary, especially in ferrous machining, where sparking and smoke are common. Mineral oil should be replaced wherever feasible with vegetable or synthetic oils. Sharma *et al.* [42] investigated how MQL procedures affected several machining parameters. Many researchers have discovered that the MQL approach produces greater machining performance than flood and dry cooling. Application of the MQL technique also improves the machining characteristics like dimensional accuracy/ surface integrity of the workpiece and reduces the wear and damage of cutting tools. Babu *et al.* [43] have observed that MQL is now widely accepted as a potential substitute for the Flood lubrication approach. This study investigated MQL cutting with vegetable oil. Utilizing Taguchi's L18 orthogonal array, investigations on AISI 304 steel were conducted. According to the analysis of variance findings, the environment plays the most role in reducing wear in tools and surface abrasion. While compared to flood lubrication, tool wear was reduced by 70% using the MQL technique. Under MQL, surface roughness (Ra) was decreased by 66%.

The effect on machinability and convective heat transfer in end milling of Ti6Al4V has been examined by Shokrani *et al.* [44] by using several additives in MQL oil, like graphite, Al_2O_3, and polycrystalline diamond (PCD). According to the findings, suspending PCD in oil enhances temperature by 43% compared to other traditional cutting fluids. High-speed machining of Ti6Al4V alloy provides a 1.6 times longer life of the tool. Improved cooling capabilities in fast-moving machining can enhance tool life, especially when thermally influenced tool wear is more severe, according to machining trials. Tanveer *et al.* [45] advanced a heat transfer model to forecast the tool hotness during machining Ti-6Al-4V using an atomization-based cutting fluid (ACF) spray coolant. With the inserted thermocouple technique, the machining trials are carried out and temperatures are measured. The experimental data were contrasted with the model's predictions. MQL method with VBCFs used by Li *et al.* [46] during the machining process of Titanium alloy TC_4. Sometimes machining of TC_4 alloy is quite hard due to its weaker thermal conductivity and great chemical activity. TC_4 is widely utilized in various industries because it contains excellent comprehensive performance. To improve lubrication and cooling properties, graphene nanoparticles were mixed into vegetable oil. The graphene addition was shown to be beneficial in enhancing milling properties. Anand *et al.* [47] have experimentally investigated the function of MQCL in turning Ti-6Al-4 V with aqueous alumina, soluble oil, and hBN nanofluids. The effect of diverse machining conditions on various machinability properties like cutting forces, tool wear parameters, efficient lubrication at the chip-tool interface, and work material adherence on the rake surface has been investigated. Investigation of the effects of manufacturing settings has been done using the overall machinability index. Due to better chip-tool interface lubrication, soluble oil in MQCL mode performed well.

Another novel lubrication method, cooling system-assisted minimum quantity lubrication (CSMQL) was developed by Ho *et al.* [48] for the milling process. In addition, to lower energy consumption, CSMQL technology enhances the machining region's cooling characteristics and improves processing quality. Cutting forces, surface roughness, morphology, chip generation, and other milling performance variables were studied in different cooling conditions. The experimental result showed that using CSMQL, the surface quality in milling was smoother than milled by other methods, and the cutting temperature was reduced by 27%.

Subramani *et al.* [49] have done numerical simulations to examine the spray properties of rapeseed oil used as a cutting fluid in MQL. For varied pressure levels, flow rates, and nozzle diameters, the spray properties of the cutting fluid were determined. Particle diameter variations are minimal in comparison to the flow rate and diameter of the nozzle. DPM is a useful technique for machining operations that uses the MQL method to determine how different cutting fluids behave. The droplet and velocity distribution of rapeseed oil was examined in this work at various air pressures, rates of flow, and nozzle diameters. This research will help manufacturers choose the best MQL system settings to minimize the cost and machining time operations while also improving the process's sustainability.

3.2 Nano cutting fluid (NCF)

Vegetable oil-cutting fluid showed encouraging results in practically every investigation involving machining. Despite the fact that VO is environmentally safe, the nanoparticles and chemicals employed in most current research are non-biodegradable and harmful. Nanofluids are used with a newly developed MQL technique, which provides effective results in different machining. Nano lubrication with higher nanoparticle concentration improves surface polish and reduces tool wear, heat production, cutting power, and consumption of power [50], [51]. Numerous academics have investigated how thermal and geometrical variables interact of nanoparticles and compared them with the thermal characteristics of the base fluid. Also, the performance of nano and hybrid NCF in various machining with the MQL method has been reviewed considering the influence of nanofluids' tribological, thermophysical, and wetting properties. Singh *et al.* [52] have reviewed many kinds of literature based on the utilization of enriched NCF particles in traditional metal-reducing operations. The impact of various nano-enriched cutting fluids on different metal cutting procedures, as well as factors influencing their process performance, are also discussed in this research.

Sharma *et al.* [53] have reviewed MQL based on various lubricating oils and nano-cutting fluids applied in different cutting procedures. MQL methods reduce the resistance due to perfect oil mist clinging to the contact zone and also reduce cutting temperature and the grinding forces of hard steel. Another development in nano-cutting fluids has been done by Sharma *et al.* [54] by stirring SiO_2 nanoparticles into the vegetable oil-water emulsion and investigating the tribological and thermal characteristics of those fluids in turning AISI 1040 at various volumetric concertations. Nano-cutting fluid may reduce the wear of the tool by 5% and 4.66% for dry and traditional mist machining respectively. The impact of MQL-Nanofluid during Ti-6Al-4V alloy cutting at a developed seizure zone has been investigated by Eltaggaz *et al.* [55] as well as the corresponding results on surface finish, tool wear, and consumption of power on it. Aluminium Oxide (Al_2O_3) was selected as nanoparticles and used at different weight fraction concentrations as nano-additives. In this study, the pure MQL technique caused adhesion on the instrument's rake face, but it was decreased while MQL-Nanofluid was present at the chip-tool contact, thus, the tool chip contact length (TCCL) decreased and created and it decreased the seizure effect. Finally, the outcome demonstrates a positive surface improvement polish and an increase in toll life when using the nanoparticle concentration. Duc *et al.* [56] showed a similar study on the milling process of Hardox 500 steel utilizing a small amount of cutting oil via the MQCL technology. Utilizing an Al_2O_3/MoS_2 hybrid nanofluid and ANOVA, Examine the influence of nanoparticle concentration, cutting speed, and input rate on surface roughness. The outcome showed improved surface quality and 2.5–2.80 times faster cutting than before.

Various cutting fluids, including vegetable, mineral, nanofluid, and synthetic and semi-synthetic oil, have to enhance machinability during milling, turning, and grinding processes using the MQL method [57]. The importance of machining fluids in improving machining factors, including temperature, tool wear, surface quality, and cutting tool life, is also discussed in this study. The remarkable quantity of reduction in machining friction and forces has got by using the MQL technique and also higher quality lubricant/coolant supply resulted in an increment in tool life. According to most studies, the ideal substitute for flooded cooling environments is a minimal amount of lubrication. Saikiran *et al.* [58] compared the outcome of machining copper alloy using vegetable-based and traditional CFs. The surface's roughness, material removal rate, the impact of CF, machining parameters, and forces were all examined utilizing both fluids under diverse conditions. The comparative result of both cutting fluids shows that the VBCF produces a superior surface finish and a higher material removal rate. The optimistic machining method may be found using the machining above parametric settings. Cutting fluid is a key element in optimizing machining parameters and material waste reduction. The main element of vegetable oil cutting fluid is groundnut oil, and traditional machining fluid is of the miscible kind. A numerical investigation of heat transfers and flow utilizing MQL nanofluid in the turning operation has been done by Khanafer *et al.* [59] using a combination of finite element analysis and a discrete phase model. Experimental validation of the numerical findings revealed a relative inaccuracy of 9.7% and 2.7% both when nanoparticles are present and absent, respectively, with a volume fraction of 2%. The average cutting tool's temperature decreased from 443 K to 420 K by adding Al_2O_3 nanoparticles.

3.3 Hybrid Nano cutting fluids

A hybrid nanofluid with superior heating and tribological characteristics is prepared by adding graphene nanoplatelets (GnP) in alumina-based nanofluid with 0.25%, 0.75%, and 1.25% of volume concentrations by Singh *et al.* [60]. Additionally, it was observed that the viscosity and heat conductivity while turning also improved as the nanoparticle concentration rose. The application of this newly developed hybrid nanofluid does better than mixed alumina nanoparticle-based cutting fluid during the machining of AISI 304 steel using the MQL approach.

Esfe *et al.* [61] did a comparative study of traditional and hybrid nano-cutting fluids for various machining operations by adding various additives. Hybrid nanofluid is found more effective than conventional nanofluid and base fluid. It is also noted that, after implementing hybrid nanoparticles in the turning, the essential criteria like cutting heat, forces used in cutting and surface roughness, and wear in the tool have positive changes up to 10%-40%. Similarly, graphene, SiO_2, and MoS_2 nanoparticles were found to be most applied and effective as per the literature. Drilling uses Cu and diamond nanoparticles most effectively. However, the nanoparticles MoS_2, Al_2O_3, and diamond families are best suited to the grinding practice. Sharma *et al.* [62] have developed and studied the performance of hybrid NCF prepared by adding Alumina-based fluid with multi-walled carbon nanotubes (MWCNTs) at various volumetric concertations. Alumina-based nano fluid's thermos physical characteristics were investigated. The hybridization was carried out at a volumetric ratio of 90:10, and in turning AISI 304 steel, a hybrid nanofluid assessed surface roughness and cutting forces. Singh *et al.* [63] looked into the impact of hybrid nano-cutting fluid in turning grade 5 Titanium alloy. The hybrid nano-cutting fluid was prepared by dispersing the graphite nanoparticles with talc in the base fluid. Considering coconut oils as base fluid, graphene, and talk nanoparticles were used in equal proportion (50:50). Surface roughness, and cutting stresses were studied in this turning operation for both the cases of hybrid nanoparticles and coconut oil compared to the result. Compared to coconut oil, hybrid nano-cutting fluid decreased cutting forces by 21.19% and surface irregularity by 18.2%.

Hegab *et al.* [64] used the MQL approach to evaluate the impact of scattering MWCNTs in vegetable oil when turning Ti-6Al-4V alloy. The uniqueness here is that varying concentrations of nanofluid were used to increase the MQL heat capacity to increase the machining properties of Ti–6Al–4V. Tool wear and power consumption during Ti–6Al–4V cutting were evaluated with MWCNT nanofluid. The result of this research concluded that using ANOVA, the number of extra nano additives was shown to be a critical design component that influences the consumption of power and flank wear. Another research examined by Jamil *et al.* [65] compares the results of two cooling and lubrication. The fundamental goal of this work is to compare the impacts of hybrid nanofluid-based MQL techniques and cryogenic CO_2 on Ti-6Al-4V conversion. Alumina (Al_2O_3) with MWCNTs distributed in vegetable oil is the employed hybrid nanofluid. Average surface abrasion was 8.72% lower, cutting force 11.8% lower, and tool life 23% lower than cryogenic cooling. Another study used hybrid cooling systems to evaluate the behavior of surface morphology and tool wear in order to improve the machining features of Al 7075-T6 alloy on a long-term basis. It has been demonstrated that the employed cooling/lubrication modes—Nitrogen cooling, Nitrogen MQL, and R-H vortex tube cooling are essential for the sustained machining of Al 7075-T6. Each C/L has, to varying degrees, enhanced quality of surface, tool wear, and chip conditions as compared to dry cutting [66]. The effectiveness of various cutting conditions was evaluated using critical machinability indicators. Findings have shown that when LN_2 and MQL are present, there is a superior cooling and lubricating effect that lowers both machining and environmental indices. LN_2 and LN_2 + MQL seemed to have a 29.01% and a 34.21% increase in cycle time and productivity compared to dry turning, respectively [67].

Padmini *et al.* [68] studied the effect of vegetable oil-derived nanofluid on turning AISI 1040 steel with MQL methods. Dispersions of nano molybdenum disulphate ($nMoS_2$) in sesame (SS), coconut (CC), and canola (CAN) oils with varied nanoparticle inclusions (npi) were used to create various nanofluid samples. Machined parameters are monitored. Experimentally, the efficacy of $nMoS_2$ has been examined in SS, CAN, and CC oils. As the NPI rose, the nanofluids' fundamental properties enhanced. A consistent rise in fundamental characteristics with changing npi does not imply that nanofluids would behave in the same way during machining. Damir *et al.* [69] have inspected the enactment of the upgraded hybrid MQL system

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in machining Ti-alloys and compared the result to conventional and cryogenic cooling. When adopting the optimized hybrid cooling approach, results showed that tool life was improved. This hybrid cryogenic cooling of Ti–Al6–4V alloy is conducted with the MQL technique. According to CFD modelling of the LN_2 and MQL jets' flow characteristics, injecting LN_2 on the flank face and MQL on the rake face is the cooling method that has the largest cooling impact. The results were validated with the improved enactment of a hybrid cooling approach in the form of wear of the tool and surface integrity when compared to other cooling techniques. A unique cutting fluid was prepared by combining Ionizing Fluids with Nano-Particles as an additive in Jatropha Oil-based vegetable oil by Sah *et al.* [70]. Six different Ionizing Fluids were mixed with Jatropha Oil at a concentration of 1 wt.%, and the thermo-physical characteristics (thermal, rheological, and wettability) were assessed. Ionic liquids-based nanofluids were effectively generated in this experiment by mixing six distinct ionic liquids with nanoparticles Al_2O_3 and ZrO_2 in Jatropha oil. The created innovative green cutting fluid was characterized theologically, thermally, wettability-wise, and tribologically. A hybrid nanofluid containing 0.75 weight percent of Al_2O_3 and ZrO_2 NPs has boosted wettability and thermal conductivity by 14.03% and 28.5%, respectively.

4 Numerical study

Numerical investigation and validation of flow and heat characteristics of various cutting fluids was done by many researchers. In a similar study, Kim *et al.* [71] used a hybrid nMQL and cryogenic nitrogen cooling/ lubrication approach to mill titanium alloy (Ti-6Al-4V). ANSYS Fluent user-defined functions (UDF) model the liquid nitrogen phase transition and heat generation during milling. LN_2 injection effectively cools the workpiece and tungsten carbide (WC) tool during the Ti-6Al-4V milling operation. The cause of increased nMQL droplets is N2 spraying in the cutting zone, improving the lubrication. Attanasio *et al.* [72] have used a new numerical approach to forecast and simulate the wear of tools in the drilling of Inconel 718 with two types of cooling. Although FEA software can estimate tool wear rates using models. To solve this constraint, DEFORM 3D, an implicit FEA programmed, created, and implemented a subroutine capable of modifying the geometry of the tool depending on a given tool wear model.

The findings of tests including a computational fluid dynamics (CFD) analysis of airflow in the grinding area during hob cutters' face surface sharpening using the MQL method are presented by Stachurski *et al.* [73]. By using simulation, it allows us to assess the impact of various spray nozzle angle fits on the quantity of air immediately reaching the grinding wheel's zone. Experimental testing was done to validate the results acquired from the numerical simulations. Uhlmann *et al.* [74]. have measured all the simulated data, as well as their preparation procedures, of different cutting fluids. This comprises process force preparation methods, chip morphology picture analysis, and determined contact lengths on the faces of tool rake. As a result, the data may be used by the reader for their own validation and analysis. In addition, the simulation model files utilized in this study have been fully shared on the Mendeley Data repository.

Klocke *et al.* [75] studied the chip formation in cutting processes which are affected mechanically and thermally by high-pressure lubricant delivery. Till date, most chip formation models have been done without taking coolant into account. This work proposes a 2D FE model that combines the simulation of fluid and structure simulation in one simulation model using a revolutionary fluid-structure interaction (FSI). High-pressure coolant effects on formation of the chip were discovered experimentally with varying pressures and impact angles in this research work. Ceramic cutting tools that are self-lubricating have lately gotten a lot of attention since tool wear when cutting hard-to-cut materials has a big impact on production costs, machined surface quality, and productivity. A rigorous evaluation encompassing a variety of elements was conducted in an attempt to summarize the progress achieved in this significant study by Akhtar *et al.* [76]. Recent experimental and computational work on self-lubricating ceramic cutting tools and the finding of potential solid lubricant consumption limits at high temperatures are examples. Ceramic cutting tools that are self-lubricating, improve tribological performance by producing a lubricating layer while cutting.

5 Conclusions

This review provides important information about published research articles related to applications of various cutting fluids, including mineral oil, vegetable oil, and nanoparticle-based used in machining operations. Numerous studies have examined how nano-cutting fluid derived from vegetable oil affects machining. VBCFs are ecological and safe for human health. Because of their high intrinsic lubricity and solid intermolecular interaction, Oil-based cutting fluids that are not edible are intriguing alternatives to typical cutting fluids. As per observations, it has been discovered that the cutting fluids employed in the MQL methods are more effective than others in machining by decreasing cutting zone temperatures and friction coefficients. Also using nanoparticles in the MQL technique enhanced the heat transfer mechanism during machining. Various experimental and numerical results revealed that combining nanoparticles with cutting fluids reduced the consumption of power, specific energy, cutting force, as well as surface roughness in the machining process. The overall effect of nanofluids under the MQL practice provides improved machining results compared to wetting and dry machining.

6 Future scope

Many research works have concentrated on the impact of Nano-cutting fluid based on vegetable oil on machining. Also, some study has been done on hybrid nano-cutting fluid in many machining uses. In the nano-cutting fluid, the MQL approach has increased the performance of tool, quality of surface, and power consumption. The heat transfer mechanism during machining by MQL technique nanoparticles is to be investigated. The work needs to continue to find the various effect of nanoparticle's concentration, their shape and size, on operating parameters in the machining. The effect of the different proportions by combinations of numerous nanoparticles (Hybrid nanoparticles) should be Investigated. In the area of cryogenic cooling, wok should continue to improve the overall cooling performance of machining.

7 Declarations

7.1 Competing Interests

No conflict of interest exists.

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