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INVESTIGATION OF CUTTING FLUID APPLICATION TECHNOLOGIES: A REVIEW

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Abstract

Health problems, higher costs, environmental concerns, and stringent environmental regulatory standards all necessitate limiting the operator's exposure to mineral oil-based cutting fluid. In industries, an incalculable amount of coolant is used every day, increasing the risk of respiratory and skin disorders. However, the usage of coolant is unavoidable due to the increasing need for productivity and job necessities. Many efforts are being undertaken to improve machining performance. Various cooling strategies are utilized in machining processes. Diverse sustainable solutions are developed in an effort to get the highest possible cutting fluid efficiency with the smallest possible amount. Among these are MQL, vegetable oils, nanofluid, iconic liquid, vapor coating, cryogenic machining, air cooling, heat pipe etc. This paper gives an in-depth look at all of the cooling and lubrication systems that are currently used and how they affect performance parameters like the surface superiority, tool wear, temperature, machining forces, etc. In addition, the research needs for future studies are identified. It is evident from the study that cooling procedures and coolant types have a considerable impact on machine performance.

Keywords: Cutting fluid, MQL, Vegetable oil, Nanofluid, Cryogenic cooling

1. INTRODUCTION

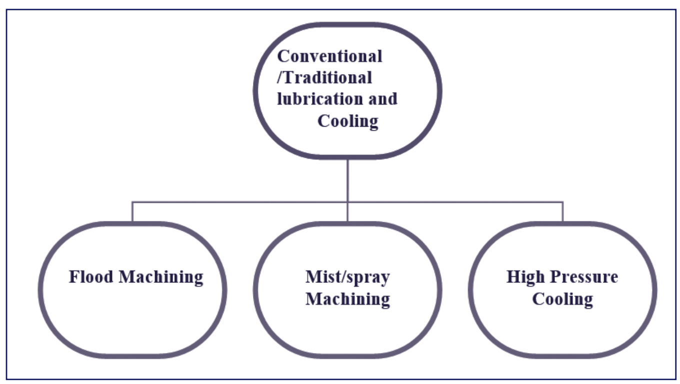
Cutting fluids are used to reduce friction and temperature throughout all machining operations. All of the coolants are responsible for getting rid of the chips. Friction reduction decreases cutting forces. Reduced cutting forces and temperatures result in decreased power usage and tool wear in all industrial processes. This improves machining outcomes in terms of higher surface quality, reduces rejection, and hence increases process productivity. It will also lower the total cost of the manufacturing process. Cutting fluids on the market are environmentally destructive and contain carcinogenic toxins. They endanger the operator. Excessive exposure to these substances might lead to life-threatening disorders. Dumping cutting fluid waste is particularly challenging since it may pollute the soil. Various regulatory bodies have established severe guidelines for the use of mineral-based cutting fluid. Efforts are being made to identify alternatives to cutting fluids. Using the developing MQL as a lubricant consumption limiter is one method. Various studies are now being conducted to examine the efficacy of different machining fluids in various machining operations. This review study outlines the various cutting fluids, the technology used to apply cutting fluid, and the impact of several alternatives on machining process performance [1].

2. LITERATURE REVIEW

2.1. Traditional Cooling/Lubrication Approaches

Cutting fluid improves machining performance. Different techniques of cooling and lubricating are used to apply cutting fluids to the cutting zone. The most widely used techniques are flood lubrication, spray or mist cooling, and high pressure cooling. These are detailed in the following section. Figure 1 shows the layout of some of the traditional techniques used during the machining process [2].

Figure 1. Traditional methods of cooling/lubrication



Flood cooling is also known as wet cooling. This method utilizes approximately 20 to 30 l/min of cutting fluids. It has been observed that due to direct contact with cutting fluid, most of the operators suffer from respiratory issues and other illnesses. The cutting fluid is circulated and then dumped into the soil. This is harmful to the environment as well as waste management of the used fluid also creates problems [3]. Oil mist is an aerosol mix of very small droplets suspended in the air and resembling fog. This mist is produced by forcing compressed air through a venturi, or vortex. Since mist cooling needs less coolant flow, it is more eco-friendly and efficient than flood cooling. Presently, scientists are attempting to develop different forms of mist cooling by nitrogen oil spray and cold compression cooling using nitrogen spray [4].

Senthil Kumar et al. (2002) conducted an experiment to compare the effects of high-pressure coolant on workpiece hardness vs dry cutting. The high-pressure coolant's ability to improve surface smoothness, reduce tool wear and cutting forces, and regulate chip form was examined. Cutting forces were lowered, surface quality was improved, and chip width was reduced when high-pressure coolant was used [5].

Zhenghui Lu et al.(2020) examined the effects of high-pressure coolant (HPC) on the cutting capabilities of HUVC titanium alloy, particularly tool life, wear mechanism, surface quality, cutting temperature, and thrust force, in high-speed ultrasonic vibration cutting. The tool life in HUVC at 200 bar HPC was 7.3 times that of the conventional cutting (CC) technique when the cutting speed was 400 m/min. Furthermore, using HPC increased the quality of the machined surface in a later HUVC cutting operation significantly. Furthermore, when compared to CC, the temperature in HUVC was reduced by 55% at 300 m/min [6]. According to Alexander et al. (1998), HPC saves cutting fluid usage by 50% and simultaneously reduces cutting temperature and force. [7].

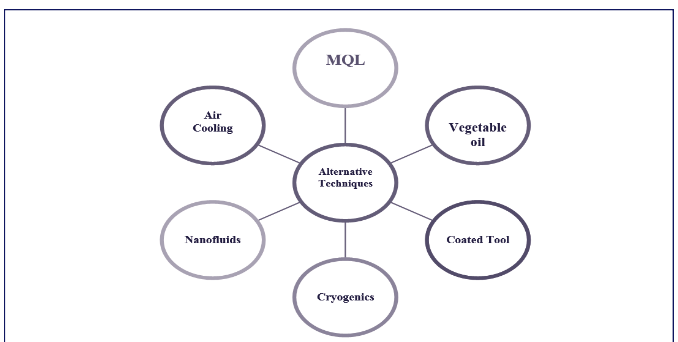
Bonney et al.(2003), machined Inconel 718 using SiC-whiskers reinforced ceramic tools at a pressure between 11 and 20 MPa. According to the findings, HPC was accountable for severe edge notching, a shorter tool life, and an increase in cutting force with an improvement in chip [8].

Srby et al.(2018) asserted that the HPC cooling technique was incapable of increasing tool life, minimizing notch wear and edge chipping, and reducing cutting force while machining Inconel 625 with a ceramic insert under 5–15 MPa coolant pressure and 200–300 m/min cutting speed. They came to the conclusion that the HPC approach is incompatible with ceramic tool machining [9].

2.2. Alternative Cooling/Lubrication Techniques

This section addresses the evolution and significance of various cooling and lubrication solutions to conventional cooling, including air cooling, coated tools, minimum amount of lubrication, vegetable oil as a cutting fluid, nanofluids, cryogenics, and others. Figure 2 gives the layout of the few alternative techniques.

Figure 2. Alternative Cooling/lubrication Techniques



Because of technological advancements in tool materials and machine tools, the use of minimal mist lubrication (a mix of air and oil) in machining production processes has become an industry need. D.U. Braga et al.(2003) evaluated the MQL (10 ml/h of oil) with air during the drilling of an Aluminum silicon alloy using a solid carbide drill (K10). The author observed that smaller holes yielded better results when roughness differences were taken into account. When drilling Aluminum silicon alloys, it was not required to use a cooling fluid because the cutting area temperature was not high enough to cause tool damage. This prevents the chip from sticking to the tool and so makes the cut easier [10]. According to Sanjeev Kumar et al.(2018), one of the solutions is to employ cooled air generated by a vortex tube. In this work, trials were performed to investigate the effectiveness of cooling air generated by a vortex tube during turning of AISI 4340 steel. The wear rate, surface finish, and thrust force were used to evaluate the machining's performance. The usage of cooling air generated by a vortex tube considerably improved tool life, lowered cutting force, and surface quality as compared to conventional operation conditions. [11].

T. Ueda et al.(2005) used experimental data to explore the effect of oil dew on tool temperature during cutting. A carbon steel tool coated with oil vapor was used for intermittent turning. The temperature of the tool during engagement was assessed using a two-color measuring instrument. The blade temperature reached 1060 °C while cutting dry at a speed of 300 m/min, but dropped to 1000 °C when lubricated vapor was delivered. According to the investigation, the tool heats up to 1060 °C while cutting dry at 300 m/min, but only to 1000 °C when using oil mist. A 60 °C temperature difference corresponds to a 50 m/min variance in cutting speed. When cutting intermittently, such as end milling, oil mist has a greater impact on tool temperature than when cutting continuously [12]. According to A.K. Sahoo et al. (2012), the three major wear processes encountered during milling are abrasion, chipping, and catastrophic failure. When cutting strong steel, an uncoated carbide insert shattered early. Under harsh cutting circumstances, tool life was predicted to be roughly 19 minutes for TiN inserts with a ZrCN coating and 8 minutes for carbide inserts with a ZrCN coating. Multilayered TiN covered inserts cost 93.4 percent less than uncovered Carbide inserts and 40% less than Zr CN coated Carbide inserts in abrasive machining with a 0.3 mm flank wear requirement. A multilayered TiN coated carbide insert offered a substantially longer tool life of roughly 19 minutes, compared to 8 minutes for a ZrCN coated insert and less than one minute for an uncoated carbide insert. The higher thrust force recorded during strong turning within the prescribed parametric range has resulted in chipping and catastrophic failure. Multilayer-coated carbide inserts done effectively at a variety of cutting speeds and cut depths. TiN coated carbides with many layers outperformed Zr CN coated carbides [13].

Micro lubrication is a viable option for environmentally friendly cutting, but there are a number of process issues to address before implementation. The researchers compared micro lubrication to dry machining and air cooling. The primary features of the MQL, such as the amount of oil, air pressure, and target distance, have been investigated in a series of tests carried out by Ling Chen et al.(2021) at the University of Illinois at Urbana-Champagne. The MQL process provided improved milling characteristics. Tool wear and cutting force were decreased, air quality was improved, and roughness was equivalent to the four processes [14].

According to Richard R. Kibbe et al.(2015), the MQL system could save a great deal of money by replacing the flood cooling strategy. The conventional approach involves costs such as water usage, a chiller, filtration equipment, a pump, and pipelines, as well as sewage treatment. In the case of MQL, this cost can be minimized. The high-pressure delivery system raises both the initial cost and the cost of keeping it running [15].

N.Dhar et al. (2006) conducted an extensive study to find out the impact of the MQL on the performance of the machining parameters. The author promoted MQL as a method for lowering environmental intrusiveness and occupational dangers.MQL's improved heat management almost eliminated notches and grooved erosion on the primary cutting edge [16].

According to J.P. Davim et al.(2006), MQL is a feasible alternative to flood lubrication systems. This article described a practical investigation that was carried out on brasses that were turned with varying levels of MQL. Turning on brass specimens was done using K10 inserts under a range of lubrication conditions. It was investigated how feed rate and speed affected cutting power, cutting force, surface irregularity, and chip shape. Furthermore, turning with and without flood lubrication was investigated. It was revealed that by employing a little amount of lubricant, performance conditions equivalent to or better than those created by flood lubrication were achieved. In all instances, the surface roughness value rose with feed rate. Ra levels in MQL rose when cutting rates increased to 200 ml/h. MQL lubrication produced equivalent or better results than flood lubrication [17].

According to N.B.Borkar et al.(2011), the metal cutting industry, which uses cutting fluid, has become more and more unsafe and polluting. As a consequence, many alternatives were studied to eradicate the usage of lubricating oil in production operations. The ideal solution to the current task is to use as little oil as possible. They chose mild steel as the work piece to investigate the issue. The author has determined three major conditions for coolant fluid: dry, wet, and MQL. They have defined four control parameters: cutting speed, feed rate, depth of cut, and tool wear. They used a bar chart and a line plot to compare the results for surface roughness and tool wear. They recommended "ANOVA" and "S/N plot" for parameter tuning. According to the author, MQL is the most important advancement in machining made by the H.S.S tool. MQL produced an improved surface quality, which subsequently boosted dimensional accuracy; this was owing to the substantial decrease in tool wear. MQL processing surpasses traditional production with flood cutting fluid supply in terms of cutting performance [18].

Ali S.M et al.(2011) validated the impact of MQL and dry cutting by comparing them to different outputs such as surface roughness, force, tool wear, chip thickness ratio, and temperature. For this experiment, medium carbon steel was used. Cutting speed and feed force are control parameters. The author examined the control parameter and the output to see whether there was a meaningful influence. By doing this experimental inquiry, the author discovered that the mean temperature of the chip tool contact could be minimized while utilizing MQL by adopting a visual method based on the work materials, tool shape, and cutting conditions. The cutting force was also lowered by MQL. The uncoated insert SNMG-120408 has reduced flank wear in MQL jet machining of steel, prolonging tool life and enhancing productivity at higher cutting speeds and feed rates.MQL improved dimensional accuracy and surface superiority by reducing tool tip wear and damage, as well as the mean temperature of the chip interface [19].

K. Abou-El-Hossein et al. (2014) used the MQL concept to create a steel specimen. The results of the MQL surface finisher were compared to those of flood coolant and dry procedures. According to the data, MQL produced a very high-quality surface. As a consequence, it was highly recommended that MQL be used instead of flood cooling for changing steel grades. According to the author, MQL outperforms flood cooling when milling steel grades with carbide inserts [20].

A. Saini et al.(2014) investigated how cutting pressures and tool tip temperature were impacted by approach angle, feed, speed, and depth of cut. 64 experiments on AISI-4340 were conducted using two different coated carbide inserts (PVD and CVD). Thus, when cutting forces and temperature are taken into account, the author concludes that MQL machining outperforms dry machining. The thin TiAIN coating on the insert generates a fine surface, which is highly advantageous for avoiding built-up edges. MQL machining generates minimal waste and uses less cutting fluid, hence reducing environmental and health risks. Furthermore, it reduces machining costs by reducing the rate of cutting fluid consumption as well as the time necessary to clean and manage wet chips [21].

2.2.1 Vegetable oil and Nanofluid

MQL significantly reduces the amount of coolant needed; however the endeavor to totally eliminate mineral-based cutting fluid results in the emergence of vegetable oil-based cutting fluid. Researchers have made use of several vegetable oils. These oils are used in conjunction with the MQL system. MQL-vegetable oil was considered to produce promising outcomes in surface roughness, temperature, cutting force, and tool life.

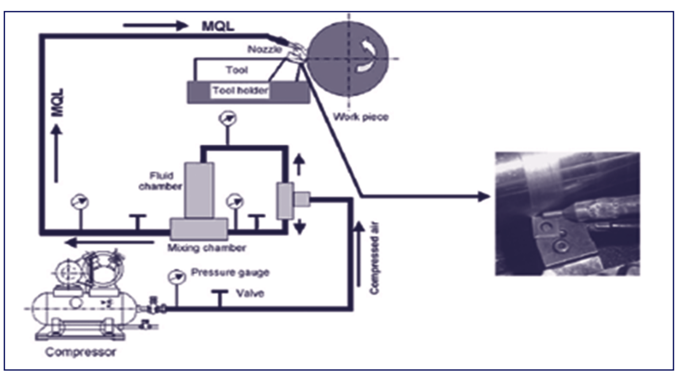
E. Kuram et al. (2010) used vegetable cutting oils to minimize thrust force and increase surface smoothness when drilling at a variety of spindle speeds and feed rates. Three different food cutting fluids were evaluated utilizing an HSSE tool on AISI 304 austenitic stainless steel. One was made from refined sunflower oil, while the other two were cutting fluids that were readily available. Spindle speed, feed rate, and drilling depth were all evaluated during the machining process. Drilling AISI 304 at a feed rate of 0.12 mm/rev and a drilling depth of 21 mm with the SCF-I resulted in the highest reduction in thrust force. SCF-II has the worst surface qualities at rates of less than 0.08 mm/rev. With increasing spindle speed, the thrust force decreased. With any cutting fluid, there was no tool wear [22].

Li Benkai et al.(2016) compared MQL grinding performance to that of base oils such as castor oil, soybean oil, rapeseed oil, maize oil, sunflower oil, peanut oil, and palm oil. Higher viscosity vegetable oil gives greater lubrication and needs less grinding effort. Castor oil has the lowest crushing power of the seven vegetable oils but the greatest crushing coefficient in terms of thermal and power ratio. Palm oil, on the other hand, grinds readily and has a low viscosity. Higher viscosity vegetable oils provided a higher lubricating effect and much lower grinding forces. The findings showed that the length of the carbon chain has no effect on the capacity of vegetable oils to conduct heat. Heat transfer was higher when the carbon chain was shorter [23]. The performance of various vegetable oils to be utilised as cutting fluid was tested by Ghuge et al.(2016) They revealed that soybean oil and ground nut oil performed better than blassocut oil. The practicality of optimization is also determined by calculating desirability [24].

Putu Hadi Setyarini, et al.(2021) used rubber seed oil is as a cutting fluid in their study, which employs the minimum drop lubrication approach. Carbide inserts and varied flow rates are used in the turning process. The results revealed that the higher the cutting fluid flow rate, lower the surface roughness [25].

According to Lizhi Tang et al(2022)., the biological stability of vegetable-based cutting fluids is a problem that needs to be addressed in order to achieve optimal performance. This research focused on the development of biologically stable cutting fluids. The bactericidal performance, toxicity, degradation rate, and economics of several sterilizing procedures were analyzed in depth, and a prospective development path for increasing the biological stability of cutting fluid was suggested [26].

Figure 3. Schematic view of the MQL (27)



M.M.A. Khan et al. (2009) investigated the effects of MQL and cooking oil on AISI 9310 machining performance in terms of chip–tool input transformation, chip formation mode, tool wear, and surface polish during both dry and wet machining. A lathe machine was used to carry out the experiment. Figure 3 shows the schematic of the MQL setup. The cut depth was kept constant throughout this method at 1.0 mm. The control parameters were cutting velocity and feed rate. Over the range of cutting velocity and feed rate tested, MQL showed predicted benefits in chip formation patterns, tool wear, and surface polish, and lower average chip–tool contact temperature. Wet cooling with a lubricant with low solubility had little influence on cutting temperature and became less effective as cutting velocity and feed rate rose. The MQL approach reduced total chip–tool contact temperature by up to 10% as compared to wet machining. The MQL jet significantly reduced flank wear while cutting low alloy steel with a carbide insert. Minimal lubrication precludes deep grooving, resulting in cutting tool failure that is both early and catastrophic. Surface finishes are enhanced as tool tip wear is reduced [27].

Gyanandra S Goindi et al. (2018) compared regular vegetable oil with hydrophilic vegetable oil and found that hydrophilic vegetable oil has a lower cutting force at a higher cutting speed and a smaller cutting condition at a slower cutting speed. Hydrophilic materials are thought to be good for better manufacturing because the fluorine in the ionic liquid can easily escape at higher cutting temperatures and stick to the chip's surface [28].

Figure 4. Vegetable oil as cutting fluid [29]

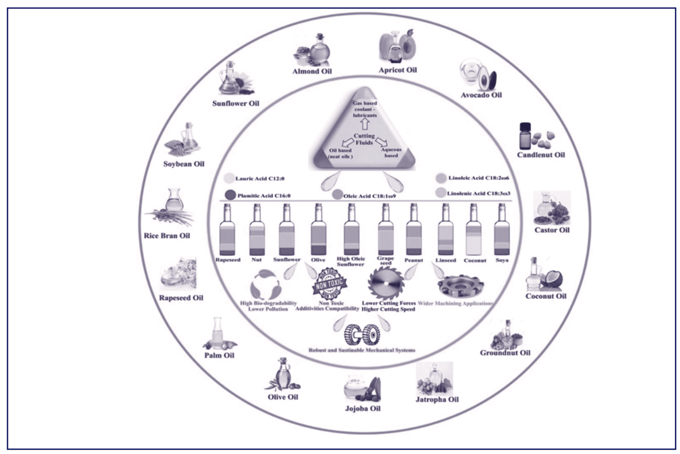
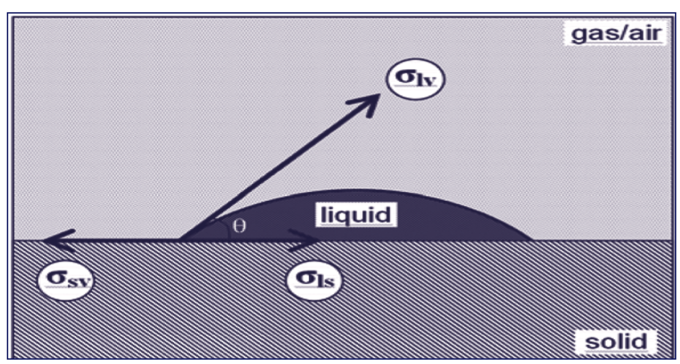


Figure 5. Schematic showing a droplet of liquid on a solid surface (30)



Sankaranarayanan R et al. (2021) explored into the possibilities of using environmentally friendly vegetable oil-based cutting fluids to achieve long-term green manufacturing. Figure 4 depicts the vegetable oils under investigation. The suitability of many vegetable oils for various metal-cutting applications was assessed and compared. Vegetable oils can substitute synthetic cutting fluids, according to this review of a study article, and this option could contribute to green machining in a cost-effective and efficient manner [29]. The performance of vegetable oil as a cutting fluid can be improved by inserting additive to improve oil properties. Many researchers are now working on examining the proportions of the different nanofulid and its impact on the machining performance.

S. Khandekar et al. (2012) provided a qualitative performance comparison of regular and nano fluids during machining. Furthermore, the influence of nanoparticles on the wettability properties of base fluids was examined. It was revealed that adding 1% Al_2O_3 a nanoparticle to standard cutting fluid enhances its wettability substantially. Figure 5 shows the schematic of a droplet of liquid on a solid surface. The remarkable reduction in crater and flank erosion was due to improved thermophysical behavior and lubricating properties [30].

R.R. Srikant et al.(2013) examined several studies conducted to reduce heat produced during the machining process. As per the study, cutting fluids remain the favored approach, but their limitations do limit their usefulness. Machining is a high-heat, high-friction operation. As compared to standard cutting fluids, a coolant must have improved cooling and lubricating capabilities. The advantages of nanofluid include higher heat conductivity and viscosity. Because of these features, they are suited for use in the metal-cutting industry [31].

Hegab et al. (2018) covered a study of all the topics related to nano-cutting fluids and their applications, including nano-fluid preparation methods, nano-fluid stabilization, the thermal and physico-mechanical properties of the nano-fluid, nano-fluid impacts on cutting performance metrics, and nano-fluid issues [32].

Li et al. (2018) used minimum quantity lubrication (MQL) with a cutting fluid based on vegetable oil in TC4 milling. Graphene nanoparticles were mixed into a vegetable oil-based cutting solution to increase cooling and lubrication. To assess the performance of the four cooling/lubrication settings, a number of milling experiments were carried out (dry, gas, pure MQL, and graphene MQL). In terms of milling force, milling temperature, tool wear, and surface integrity, the milling parameters of TC4 were investigated. The use of graphene improved milling characteristics significantly. Overall, the findings suggested that adding graphene to the milling zone oil coating would improve cooling and lubrication [33].

As per the research of Chatha S.S et al.(2016), C140H42O20 nanoparticles reduced thrust force (27.34%), torque (64.9%), Ra (33.8%), and friction coefficient (51.7%) in the 30th hole as compared to the natural MQL condition. Sufficient C140H42O20 nanoparticles in nano-fluids MQL drilling improved film lubricants and dependability, resulting in improved drilling quality. Food oil nanofluids were a novel type of cutting fluid that could be used in drilling applications instead of traditional oil-based MQL. This was due to the fact that a sufficiently high concentration of nanoparticles in base oil stimulates the creation of a thick lubricating layer, which increases heat transfer. C140H42O20 mixed vegetable oil is a novel form of cutting fluid for drilling applications that uses nanoparticles to increase drilling process sustainability and cooling capabilities to replace standard rock oil-based cutting fluids. When graphene nonmaterial was added to foundation oil, erosion was reduced and drill bit life was increased when compared to the pure MQL approach. The high concentration of nanoparticles in the oil enhanced its viscosity [34].

P.B. Patole et al. (2018) used the MQL approach to perform research on surface quality. They used a CNC lathe. The effect of MQL settings on the Ra of AISI 4340 was investigated using MWCNT nanofluids. They investigated this experiment using three control parameters: pressure, flow rate, and coolant type. Coolant was a mixture of MQL 1 C2H6O2 combined with a nanofluid and MQL2 H2O combined with a nanofluid. They planned their experiment on an L16 OA. The data was evaluated using an ANOVA. According to the results, the most important factors influencing Ra decrease were cutting fluid, flow rate, and pressure, with pressure having the least impact on surface texture becoming excellent under MQL employing nano coolant. The variation in surface roughness between experimental and predicted values is less than 10%. Inserts coated with WC, class K10, and standard CCMT 090308 were utilised to improve the machining characteristics of AISI 4340 during the MQL process. When compared to H2O, $C_2H_6O_2$ as a working fluid mixed with nano fluid yields better results [35].

Shokrani et al. (2021) evaluated the influence of several contaminants on convective heat transfer and machinability in Ti6Al4V end milling, including Al2O3, polycrystalline diamond (PCD), and graphite, as well as water in MQL oil. When compared to normal MQL, eliminating PCD from oil improved heat transfer by 43%, according to the trial. This might result in a 1.6-fold improvement in tool life while cutting titanium alloy at high speeds. The effect of floating various additives in MQL oil on Ti6Al4V titanium alloy high-speed end milling is examined. The study revealed that Al2O3, PCD, and graphite suspended in oil increased the rate of heat transmission. Increased cooling capabilities have been found in machining experiments to greatly extend tool life. This was also apparent in case of power usage and the bending moment of the tool assembly [36]. Figures 6 and 7 shows the convective heat transfer coefficient for the various combinations.

Figure 6. Convective heat transfer coefficient for various MQL CL (36)

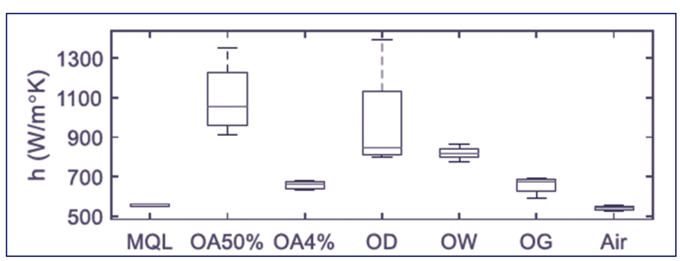
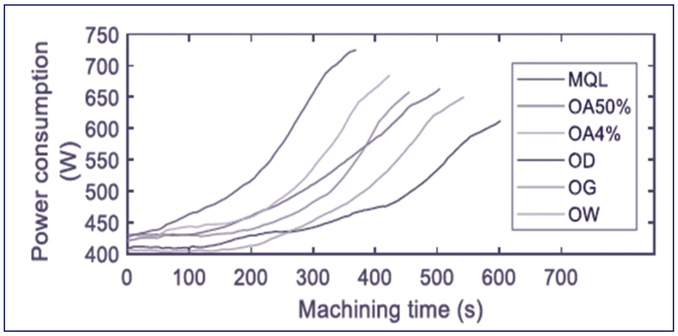


Figure 7. Power consumptions for various MQL CL (36)



2.2.2. Cryogenic cooling

Y. Yildiz et al.(2012) gave overview of cryogenic cooling. Cryogenic cooling with liquid nitrogen is a technique that does not pollute the environment in any way. Liquid nitrogen captivates heat from the manufacturing process and rapidly evaporated. The fluid evaporated during cryogenic freezing by carbon dioxide, and while the concentration of carbon dioxide evaporated was small. Cutting fluid residues were removed from machine parts and chips as a result of machining, lowering treatment costs. Furthermore, the compounds employed are non-toxic and therefore do not cause fog [37].

According to H.Chetan(2016) and his colleagues, gaseous cooling has the same advantages as cryogenic cooling because both are considered to be some of the most environmentally friendly and clean ways to mill various technological alloys after dry machining [38].

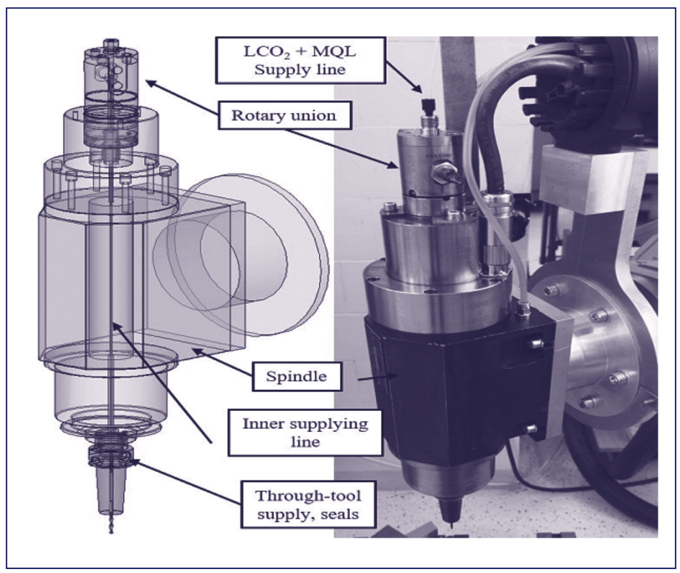
D.A. Stephenson et al.(2014) collected preliminary data on the use of super - critical CO2 MQL as a flood coolant in an outward CNC lathe with an Inconel 750 spindle. ScCO2 MQL improved the tool's life or rate of material removal when machining Inconel 750 and related nickel alloys by enhancing lubricity and altering the principal wear process away from fast notch wear and toward slow crater erosion and chip smashing. Notch wear was greatly reduced in the presence of ScCO2 MQL, although craters and hammering were much more obvious. This study showed that MQL processing can be utilized to manufacture a difficult-to-machine metallic alloy. As a result, the author determined that when hard turning Inconel 750 at 48.7 SMM and 0.20 mm/rev, CO2 MQL gave a longer tool life than soluble flood coolant. Under these circumstances, a CO2 air flow rate of roughly 70 g/min is enough. When used in combination with carbide tools for fuzzy turning, Inconel 750, Inconel's supercritical CO2 milling machine (SCCO2 MQL) boosts material removal rates by 25–40%. CO2 MQL increased flow ability and shifted the wear mechanism away from rapid groove erosion and toward gradual crater wear and chip hammering [39].

T. Bergs et al. (2019) mentioned how cryo chilling in combination with MQL is simply a dependable approach to boost efficiency when cutting difficult metals. The high-tech approach was a single-channel method that makes use of oil solvation in supercritical CO2. Fluid carbon dioxide (LCO2) was easier to handle and more widely available. For the purpose of machining Ti6Al4V, a one-of-a-kind single channel system capable of linking LCO2 and MQL has been created and tested. Rhenus LA722139 was discovered to be more CO2 solvent than Rother lubricant c-ti. The two-channel technique resulted in a reduced tool life when compared to flood lubrication [40].

According to D. Grguras et al (2019), the physiochemical properties of oil have a substantial influence on its absorption in LCO2. The development of a single-channel, pre-mixed LCO$_2$ and oil delivered by MQL represented a significant advancement in cryo metalworking methods. The rate of evaporation influenced the size and circulation of the oil phase as well as the tool's life. A revolutionary technique for mixing any liquid lubricant into a fluid CO$_2$ flowing without the need for extra CO2 has been developed. Solvated oils are highly soluble in LCO$_2$, allowing for smaller droplet sizes and more even dispersion, which results in better lubrication [41].

Using CO2 – MQL cool lubricated, a novel method for monitoring heat and cooling fluxes during the milling process has been developed by T. Augspurger et al.(2019) The device included a monitoring system to relay the temperature sensed by a thermocouple placed on the tool. Additional data analysis was utilized to determine heat transfer into the device by comparing observed temperatures to analytically anticipated transient temperatures [42].

Figure 8. Spindle adaptation for through-tool LCO2 + MQL supply (43)



L. Sterle et al. (2021) investigated the effects of LCO$_2$ cooling, MQL and cutting speed on drilling as shown in figure 8. Torque, thrust force, and temperature are measured under a range of manufacturing and operating conditions. The experimental simulation experiments were used to assess the different influences of each of these factors. The drilling of 42CrMo4 steel with the help of LCO$_2$ and MQL was studied. The author examined and tweaked the cooling, lubrication, and cutting conditions. LCO$_2$ cooling improved chip evacuation by increasing pressure. By minimizing friction between chips, drill flutes/hole walls, and at the cutting edge, MQL greatly increased torque reduction and stability. LCO$_2$ flow rate must be tuned for the cutting circumstances and MQL scenario utilized to attain the greatest performance [43].

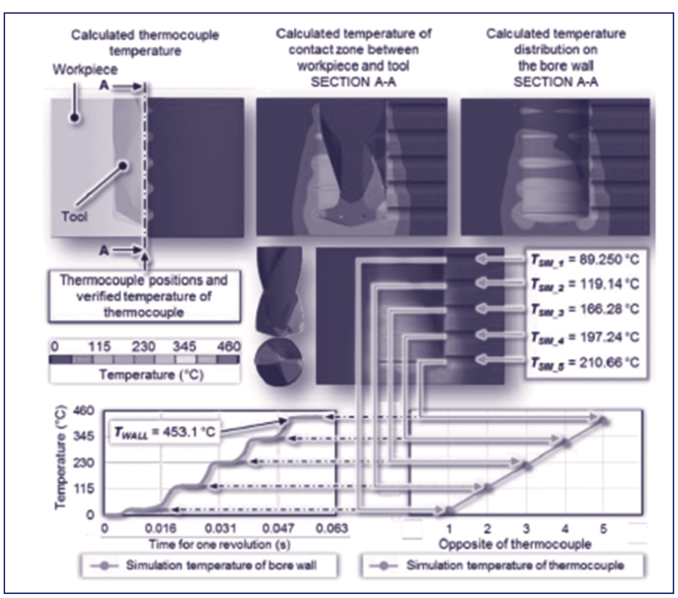
Y. Kaynak et al. (2015).investigated the lubricating technique with time intervals ranging from 1 to 4 minutes. They looked at the effects of manufacturing (vacuum arc remelting against vacuum induction melting (VIM +VAR)), processing (hot rolled + totally annealed versus cold worked + super elastic anneals), and machining conditions (dry, cryo, and MQL). Cryogenic machining greatly improved cutting tool performance by minimizing progressive tool wear during room-temperature processing of austenitic NiTi alloys. As stated by the author, MQL and dry machining were not superior to cryogenic machining since the cutting and tool wear processes in dry and MQL were quicker than in cryogenic machining. Cryogenic machining resulted in more homogeneous and smooth surface feed marks. According to the study, NiTi alloys containing TiC particles had significantly poorer tool life than alloys without these particles. According to the findings of this research, using carbon-free NiTi alloys gives an advantage in terms of machinability. According to recent research, cryo processing is the best way for boosting the processability of this alloy since it reduces tool wear significantly. However, after four minutes, all three machining processes produced surface roughness that was essentially equivalent [44].

Liew P et al. (2021) provided a critical assessment of the literature on cutting fluids and cooling techniques for hardened steel turning. The author focuses on wet cutting, high-pressure cutting, MQL dry cutting, and cryo cutting as well as other technologies. They also suggested that hybrid technology be investigated further [45].

3. MODERN WAY OF LUBRICATION/COOLING

E.Oezkaya et al. (2019) examined the impact of fluid flow and channel diameter on the fluid channel. To augment the studies, CFD experiments were employed.

Figure 9. Tool Temperature Simulations (46)



CFD and FSI are appropriate approaches for conducting a comprehensive analysis of the drilling process. Increased channel widths have little effect on lessening the high heat loads associated with Inconel 718 drilling because the increased coolant flow supplied by a bigger refrigeration system is largely centered in the groove and dead zones at the sharp end still persist. Raising the pressure on either side led to greater flow rates, which resulted in an increased rate of heat transfer, resulting in a prolonged tool life owing to improved internal cooling conditions as shown in figure 9 [46].

Recep Demirsöz et al.(2020) investigated the tribological behavior of 316 L stainless steel versus 100 Cr6 alloy under different cooling conditions. A ball-on-flat tribometer was used to conduct tribological testing on additively manufactured 316 stainless steel under dry, MQL, cryogenic, and hybrid cryo+MQL conditions. Following that, the most essential tribological characteristics, such as friction forces, volume loss, wear depth, and micrographs, were examined. Combining cryo and MQL cooling settings increases tribological performance while controlling material volume loss and wear rates, according to the research. MQL, cryo, and dry conditions were outperformed by the cryo+MQL condition [47].

According to R.L. Javaroni et al.(2022), the MQL approach's application is still limited due to the repeated incidence of overheating and disc obstruction during grinding. MQL needs to be improved before it can be utilised in a variety of grinding operations. The purpose of study was to investigate the effectiveness of a cooled wheel cleaning jet (CWCJ) combined with the MQL while cutting AISI 4340 hardened steel. Trials employing the usual MQL+WCJ technique were undertaken as a comparative. The MQL+CWCJ technique surpassed the standard MQL method in all parameters studied, decreasing wheel wear by up to 98 percent, surface roughness by 70%, roundness deviation by 81%, and grinding power by 30%. The MQL technique worked poorly because of insufficient cooling and a restricted chip removal capability, resulting in increased wheel obstruction [48].

Franci Pusavec et al.(2020) revealed that solid-lubricated LCO_2 surpasses other types of lubrication. Tribological measurements were used to evaluate the coefficient of friction between an uncoated carbide implant and the substrate. The topography of the final surface was examined using an elevated scanning electron microscope, which revealed no adhering solid particles on the workpiece's surface. When compared to emulsion, the friction coefficient between both the cutting work piece and the breakthrough solid-lubricated LCO_2 technology is lowered by 0.25 to 0.09. (64 percent reduction). Machining using solid lube produced a dry method that eliminated the need to clean and/or deep clean machined surfaces. MoS_2 solid particles showed the ability to form tribofilms in the contact zone [49].

A.N. Mohd Khalil et al.(2021)explored the influence of different MQL combinations on NiTi alloys using aluminium oxide particles in SolCut oil. As per data, combining nano MQL with cold compressed air reduced tool wear and cutting force significantly. But, the cutting force generated by this hybrid state was far greater than that generated by micro MQL, especially at speed of up to 25 m/min. However, in terms of reducing heat just at the cutting area, this combination surpasses micro MQL [50].

I. Kantharaj et al. (2021) invented a novel technology for removing heat from the manufacturing process. Heat pipes inserted in cutting tools are used to dispel the extra heat generated at the tool-workpiece interface. The machining that is done with these tools is done in a dry environment. This method of using heat pipe-embedded tools has been designed, built, and tested for a range of machining techniques, and it has proved suitable for industrial applications. It was also explored how to increase the surface quality of the manufactured items as well as the tool life. Interesting effects, such as a decrease in cutting force while utilizing such instruments, are also mentioned. [51].

Wu X et al.(2021) conducted a thorough examination and evaluation of various cutting fluid technologies as well as the evolution of green manufacturing technology. The author concentrated on the technological challenge in the research accomplishments of eco-friendly cutting fluid and waste fluid management. The author concentrated on the technological challenge in the research accomplishments of eco-friendly cutting fluid and waste fluid management. Production of an amino acid additive, a self-adapting jet parameter supply system, and a fitting technique among processing conditions and cutting fluid were suggested, laying the groundwork and offering aid for cutting fluid research and innovation [52].

X. Li et al. (2014) designed a self-inhaling cup segmentation disc that reduces grind heat by about 50%. According to the research, reducing the polishing surface temperature by 30% or more improves grind effectiveness. The use of self-inhaling wheels improves grinding performance while reducing surface burn. When combined with external and internal cooling, a segment disc with a self-inhaling structural cup form has the ability to significantly lower temperatures. The temperature drop caused by the use of a water-based semi-synthetic fluid may help to reduce grind heat and increase machining efficiency, lowering the risk of surface grinding burn. A segment disc with a self-inhaling structural cup form, when combined with external and internal cooling, has the ability to significantly lower temperature [53].

V. S. Sharma et al.(2009) gave an overview of the major advancements in methodologies like minimum quantity lubrication (MQL)/near dry machining (NDM), pressurized coolant (HPC), cryo cooling, compressed air cooling, and the use of solid lubricants/coolants. These processes reduced friction and heat in the cutting area, increasing process productivity [54].

Pralhad B. Patole et al. (2021) offered a complete evaluation of the research on cutting fluids and cooling procedures for hardened steel turning.. The author mainly focuses on the different technologies like wet cutting, high pressure cutting, MQL dry cutting and cryogenic cutting. They also recommended the hybrid technology for further research [55].

CONCLUSION

This research article provides a brief overview of significant research efforts to discover a solution for the replacement of mineral-based cutting fluid. This analysis also includes an examination of the various technologies employed to remove the harmful cutting fluid. It also highlights the research conducted by many writers to assess the performance of machining operations employing various cutting fluids. The primary goal was to decrease cutting fluid exposure. Based on this need, many methods utilizing less cutting fluid than flood cutting are being developed. Minimum Quantity lubrication has been shown to be the most effective strategy for reducing operator contact with cutting fluid. Many studies employed mineral-based cutting fluid with MQL and demonstrated a significant increase in machining parameters as well as cost savings. Considering environmental standards, attempts were made to replace harmful cutting fluid with vegetable oils such as soyabean, sunflower oil, and so on. Rubber seed oil is also being considered as a feasible option. In terms of temperature, surface roughness, and cutting forces, the use of vegetable oil as a cutting fluid in a MQL system produced promising results. The use of nanofluids, non-edible oil, and solid-lubricated LCO2 improved work piece qualities as well. Using heat pipes also showed improvement in heat rejection. Cutting fluid stability and purification are the main concerns, and many researchers have given solutions for them. Multinational companies use MQL technology with bio lubricant in the majority of developing nations. On the other hand, small businesses are unaware or reluctant to use the different technologies available in the manufacturing field. The greatest impediments to the industry's expansion are illiteracy and a cavalier attitude toward employee health. The MQL systems on the market are expensive. There is a need for MQL systems and cutting fluids that aren't too expensive and can be bought by small manufacturing units.

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