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STUDY OF THE PERFORMANCE OF VARIOUS CUTTING FLUIDS USING MQL TECHNIQUE IN VARIOUS MACHINING PROCESSES ON ALLOY STEEL: A REVIEW

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ABSTRACT

The cutting fluid is an integral part of any metal machining process, as it cools the workpiece, and the cutting tool flushes chips out of the cutting zone and lubricates the tool-to-workpiece interface. Still, the cutting fluid is potentially hazardous to both human and environmental health if misused or disposed of improperly. However, issues with production rate and environmental impact are brought to light by using an excessive quantity of cutting fluids. Manufacturers strive for a less hazardous workplace and lower production costs by using less cutting fluid in their machining processes. Minimum quantity lubrication (MQL), in which we feed the lubricant at a highly modest flow rate to the machining zone, is a practical approach to reaching this objective. There is proof that the MQL method may be used to accomplish "Green Machining" since it aligns with the standards set forth by that term. "Since this is the case, this research examines the outcomes of MQL in turning, drilling, grinding, and milling applications using mineral oils (base oils), vegetable oils (synthetic oils), and Nanofluids." Compared to flood lubrication, the MQL approach has shown to be effective in the same situations.

***Keywords**: Nano-lubricants, cutting fluid, Prolong Tool Life, MQL & Green Machining.*

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I. INTRODUCTION

The impacts of climate change in recent years have expanded beyond the physical environment and ecosystems to encompass alterations to the economy and social structures of human society. One of the dangers to sustainability is global warming produced by humans. In the metal-cutting sector, eco-friendly machining is gaining attention. “One of the best ways to lessen damage to the environment and people's health is to reduce the amount of cutting fluids used. Up to 85% of cutting fluids are produced from mineral oil [1]; therefore, discharging them into the environment without recycling them is very detrimental.” Howevelready high cost of producing the product is exacerbated by the high cost of trng the waste oil.

Therefore, academics throughout the globe are becoming more concerned about the possibility of lowering the usage of these oil types and replacing them with biodegradable oils, such as vegetable oils. “Cutting fluids profoundly supplied into the cutting zone, along with the use of tiny oil flow rate, will bring about not only technical efficiency but also economic advantages, and this trend is mirrored in the cooling and lubricating technology.” To be specific, MQL is an organically developed technological innovation. Very high lubrication efficiency is achieved by employing nozzles and high-pressure air flow to spray cutting fluid directly into the cutting zone at a rate of just 5–500 millilitres per hour [2]. However, the MQL process is eco-friendly because of the small quantity of cutting fluids used.

Research on MQL technology in machining has been extensive during the last four decades. Many writers have argued that MQL conditions provide superior cutting performance and surface quality compared to dry and flood conditions. The correct settings for MQL's parameters are crucial for its effective implementation. “Many researchers have examined and reported on MQL factors such as cutting fluid type, oil flow rate, air pressure, air flow rate, nozzle location, spray angle, number of nozzles, etc. Oil-in-water emulsion [3, 4], vegetable oil [5, 6], synthetic ether [7, 8], and so on are all examples of regularly used oils.” Because of their increased molecular weight compared to mineral oil, vegetable oils are a good choice among these cutting fluids for their ability to reduce friction and wear. Because they are botanical in origin, these oils are also environmentally friendly, user-safe, and non-polluting [7, 8]. In light of this, vegetable oils are well suited for MQL technology since they provide adequate cooling lubrication and preserve environmentally benign features, making them ideal for the advanced machining industry of today. Consequently, scientists and manufacturers are showing much interest in this line of inquiry [1, 2, 3, 9, 10].

Regarding MQL, air pressure is a significant factor that significantly affects the machining process. Coolant cannot go deep enough into the contact area to provide enough lubrication when the air pressure is not high enough. Therefore the cooling and lubricating efficiency could be better. Not only will this decrease surface quality and tool life, but it will also prevent the chip from being removed from the cutting area. If the air pressure is too high, however, the chip is driven out of the cutting zone smoothly and deeply, carrying the cutting oil into the cutting zone without enough time to build the oil film. This reduces its ability to act as a lubricant. So, finding the sweet spot for air pressure optimal for every kind of cutting takes work. The results of our efforts are seen in [11].

A comprehensive report on MQL factors such as spray angle, flow rate, air pressure, and nozzle placement can be found in [12]. The results showed that the size and distribution of the droplets depended on the injection

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pressure as well as the location of the nozzle. A hydrodynamic lubrication layer is created when oil is produced between contact surfaces (rake face and chip, flank face and machined surface). This is the most remarkable advantage of the MQL technique for metal cutting, among many others. Oil film formation efficiency was shown to be significantly impacted by nozzle positioning. The flow rate determines how much closer the droplets are moved to the cutting zone [13]. The effectiveness of cooling lubrication in MQL technology has been the subject of a recent exploratory study [14].

II. LITERATURE REVIEW

Jia et al. [15] conducted a study in which they examined the outcomes of a surface grinding operation conducted in a variety of cutting settings. Nanoparticle jet MQL outperformed the other three cutting conditions. The MoS2 nanoparticle had the most significant anti-attrition impact of the three tested nanoparticles. Amrita et al. [16] studied the effectiveness of three nanofluids, and the findings were compared to those obtained under dry and MQL cutting circumstances. Compared to dry and MQL machining, nanofluid-based machining fared better in every category.

The combination of lower friction and chip bending away from the cutting zone owing to high-speed air results in a minor chip with cryogenic compressed air cooling and a giant chip with compressed air cooling, as studied by Sun et al. [17], compared to dry machiniCompressedcompressed air or cryogenic compressed air reduced flank wear and the inclination tobuilt-upa built-up edge. Khandekar et al. [18] evaluated three distinct cutting settings concerning a variety of machining parameters. The findings demonstrated that nanofluid machining is out of conventional fluid and dry machining.

Roy and Ghosh used different cutting conditions in the high-speed turning operation conducted on 4140 steel [19]. Cooling and heat absorption compound to be much higher with nanofluid MQL than with dry and flood coatings, Liu et al. [20] examined two green production procedures for machining titan using two different types of nanocomposite coatingsium alloys. Tool wear was reduced more by MQL machining than dry machining.

When compared to (NC-AlCrN)/(a-Si3N4) coating, the performance of the (NC-AlTiN)/(a-Si3N4) coating composite was superior. Padmini et al. [21] compared the performance of micro and nano-solid lubricants suspended in vegetable oils during rotation. Suspended cutting fluid with nanoscale solid lubricants surpassed microscale solid lubricant cutting fluid in every metric. “The grinding process was carried out using nanofluid by Zhang et al. [22].” The team examined the data from the numerous sensors and compared the findings to those from other machining scenarios. The experimental results showed that nanofluid machining outperformed conventional cutting methods.

Amini et al. [23] evaluated the impact of near-dry machining on tool wear while turning AISI 4142 alloy steel. He conducted studies and discovered that tool life in near-dry machining is more significant than in dry machining. It also had a good effect on the surface roughness, allowing for more excellent cutting rates using the MQL approach than with dry machining. Turning and milling titanium aluminides with a low amount of lubrication was studied by Priarone et al. [24], who found that dry machining was the most durable cutting condition when compared to standard flood cooling and wet machining. However, Th also showed that a

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moderate drop in process parameters was necessary to maintain process stability. MQL milling provided good results for tool life, but wet circumstances proved to be the best option for turning.

During the rough turning of Inconel 750, Stephenson et al. [25] analyzed the effectiveness of two different cooling methods. A greater material removal rate and longer tool life een using supercritical CO2-based MQL instead of flood cooling. Sodavadia and Makwana [26] made three nanofluids from coconut oil. Experiments showed that the Nanofluid with a 0.5% suspension of nano boric acid was particularly effective.

Cutting forces, cutting speed at the chip networking tools, tool wear, and surface roughness for each revolution were all identified by Amrita et al. [27] as indications of a fluid's performance in their investigation of emulsifier oil-based nano-cutting fluids for metal cutting. The rolling action of billions of nanoparticle units at the tool chip interface dramatically lowered cutting forces in a study by Rahmati et al. [28] of CNC milling of AL6061-T6 alloy using a molybdenum disulphide (MoS 2) nano lubrication method.

MQL turning, including nano graphite inclusions, was put to the test on AISI 1040 steel by Srikant [29]. Nanoparticles in water were chosen to be present at a range of weight percentages: 0%, 0.1%, 0.2%, 0.3%, and 0.5%. Five millilitres per minute, ten millilitres per minute, and fifteen millilitres per minute were among the various flow rates considered. Cutting forces, temperature, and tool flank wear were all reduced, while surface roughness improved once nano graphite was included. A further modification of viscosity by nanoparticle concentration was observed. The higher the viscosity, the more lubricating qualities it will have. Increases in thermal conductivity accompany increases in nanoparticle incorporation. However, a potential drawback is that an increase in nanoparticle content may cause a shift in the solution's pH. An optimal pH may promote the development of potentially dangerous bactericides, humectants, and germicides.

When it comes to hobbing, Khalilpourazary and Meshkat [30] looked at how alumina nanoparticles affected the roughness of the spur gear surface and how long the hobbing tool lasted. Alumina nanoparticles were mixed into a 25 W50 base oil from mineral sources. He considered both the "with lubri- cants" and "without lubricants" scenarios. He discovered that using nanofluids led to a general trend of lowering surface roughness (Ra) during the manufacturing of spur gears, even if the ten-point mean roughness (Rz) was not substantially different between lubricants. In the cases of tool crater wear and flank wear, promising results were seen thanks to the rolling action of nanoparticles, which prevents the generation of thermal stress. Sayuti et al. [31] investigated using SiO2 nanoparticles, in the end, milling with aerospace Al6061-T6 alloy. The experiment aimed to establish the best lubricant for the machining zone in terms of maximizing tribological qualities. Sizes of the nanoparticles ranged from around 5 to 10 nm. When using nanoparticles dispersed in mineral oil, high air stream pressure, and an orientation angle of 60 degrees at the nozzle, it was discovered that cutting force could be lowered by 0.2% wt. Cutting temperatures were found to be lowest for the mineral oil with the fewest nanoparticles.

Kumar and Ghosh [32] looked into making multi-walled carbon nanotubes (MWCNTs) using an alumina grinding wheel and evaluating their efficacy. The MWCNT concentration in the solution was 1% by volume. Compared to soluble oil, the Nanofluid was found to have a thermal conductivity that was 35% greater in the studies. Substituting MWCNT for the soluble oil reduced the grinding temperature, as shown by an increase in the proportion of long and sheared chips and a decrease in the proportion of spherical chips.

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Su et al. studied the thermophysical properties of graphite-based nanofluids [33] using AISI 1045 medium carbon steel in a cylinder-turning experiment. It was shown that both the cutting force and temperature could be significantly reduced by employing Nanofluid. The highest reductions in main cutting force from dry machining occurred at feed rates of 55, saving 11% and 26%, respectively. The use of nano lubricant alone, without any other additives, has resulted in agglomeration over time. The result is the introduction of a new class of chemicals called surfactants. These amphiphilic chemicals may accumulate at the boundary between two incompatible fluids, their tension between them. As a result, hydrophobic or insoluble organic molecules are made more soluble, mobile, bioavailable, and eventually biodegraded [34].

Straight oil fluids give the optimum lubrication and machining perfomostajority of machining settings. They are made up of chosen boundary lubricating properties dispersed or solvated in natural mineral oils and are used for lubrication in machining operations like broaching and deep hole drilling [35].

Rajmohan et al. [36] suggested two distinct kinds of cutting fluids for turning stainless steel specimens. Adding a nano-particle to the cutting fluid improved its cooling and lubricating properties. The experiment findings showed that feed was the most critical factor in determining the cutting force.

When turning Titanium alloy with CBN inserts, Gupta et al. [37] analyzed the results using three different nanofluids. During the experiments, the variables that had the most impact on the outcomes were the rates of feed and chilling. The angle of approach had little role in the outcomes. Compared to the other two nanofluids, the graphite-based Nanofluid was shown to have the most impact on surface quality.

III. MINIMUM QUANTITY LUBRICATION (MQL)

Minimum quantity lubrication (MQL), or near-dry machining (NDM), as described by Astakhov [38], is a method for delivering lubrication fluid in the form of microscopic particles to the cutting area. With the help of compressed air, a smaller quantity of lubricating fluid is transported to the machining and turned into microscopic particles through orifices (atomization). These minute particles are delivered to the machining area as aerosol, a gaseous suspension of liquid particles. Figure 1(a) below depicts a hypothetical MQL scenario in which the air delivers an atomized oil particle to the tool's operating area.

IV. CLASSIFICATION OF MINIMUM QUANTITY LUBRICATION SYSTEM

Typically speaking, there are two distinct MQL architectures. Internal systems are the earliest variety. “An internal system consists of a mixing chamber where oil and air are combined before being sent to the cutting zone through a single nozzle pipe.” In contrast, the sea, known as an external system, uses an oil-air combination at the nozzle tip and creates airborne particles immediately after that. In order to get the oil to the cutting zone, it is pumped in tiny amounts via a pipe to the nozzle's tip, which is then pushed by air rushing through yet another pipe. The diagram below, Figure 1, shows the critical distinctions between the exterior (T-1) and internal (T-2) systems (b).

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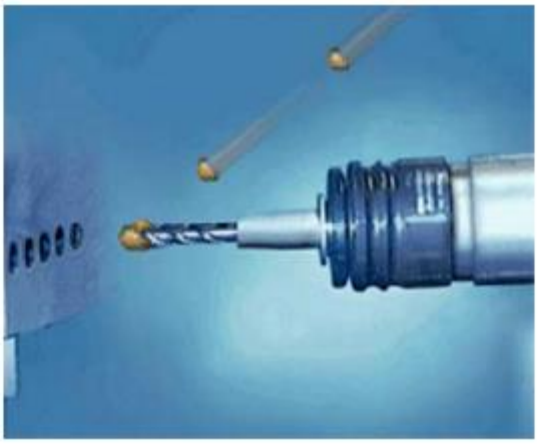

Figure 1(a): A Perfect MQL Model.[38]

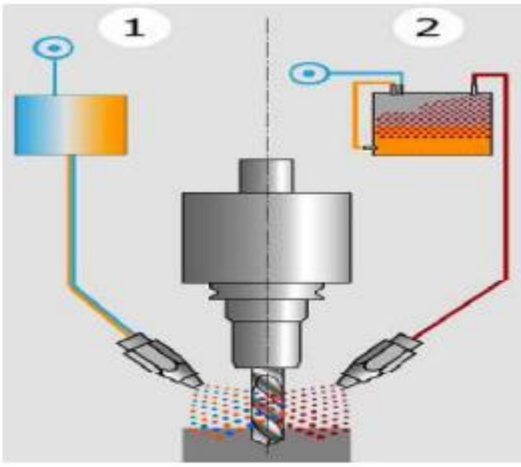

Figure 1(b): There are two kinds of MQL feed systems: external and internal. [38]

V. APPLICATION OF MINIMUM QUANTITY LUBRICATION (MQL) IN MACHINING PROCESSES

When it comes to fundamental machining operations like turning, milling, drilling, and grinding, the MQL approach shines. In addition, it may be used to cut a wide variety of workpiece materials, including steel, aluminium toughened material, and other difficult-to-cut substances. The MQL technique, when combined with resin bond corundum, has been proven to be superior to both wet and dry machining in terms of the quality of the grinding operation it produces, as reported by Tawakoliet al.[39]. Grinding operations using the MQL approach may provide surfaces with acceptable integrity (roughness, residual stress, microhardness, and microstructures). Some restrictions apply to the usage of MQL in closed-type procedures like drilling because of this. The airborne particles that act as a coolant and lubricant for the drill tip have a hard time making it to the bottom of the hatch is what causes thiInternalng internal cooling/lubricating tubes that provide coolant inside is one way to get around thiCompareden compared with cutting with an external cooling supply; it cuts temperatures by approximately half. Traditional methods like wet machining are being phased out in favour of more sustainable alternatives like dry and near-dry machining in response to tight environmental rules and

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the rising cost of cutting fluid acquisition. One alternative to meeting environmental standards is MQL rotation.

VI. MQL TECHNIQUE FOR VARIOUS MACHINING PARAMETERS

System and cost are not issues for any MQL system. For this reason, many MQL delivery systems have recently entered the commercial market using a broad range of designs and technology. MQL tools are often found in brand-new, high-tech machine tools. Because of this, the requirements and investment cost limitations should be considered while making the equipment decision. Several case studies in the literature compare MQL to flood cooling and dry machining to learn more about the benefits of using MQL in the machining process for a broad range of workpiece materials. Other parameters for various machining techniques are discussed in this section.

- **Minimum Quantity Lubrication Application in Turning Processes**

Researchers and R&D departments in the manufacturing sector are now working to demonstrate the impact of machining parameters on MQL performance via process modelling and optimization. However, no significant differences were discovered between MQL and dry machining in the early days of its application in the machining process. In their experimental study, Itoigawa et al. [40] turned aluminium alloy using a computer-numerically controlled lathe. “Lubricants included rapeseed oil and synthetic esters (monocarboxylic acid with polyalcohol).” Their research determined that MQL with an oil coating on a water droplet provides enough lubrication when using a suitable lubricant such as a synthetic ester. Khan and Dhar [41] used vegetable base oil to test MQL's performance characteristics when turning AISI-1060 steel. Their research shows that performance and dimensional correctness are enhanced when MQL is used instead of dry or straightforward cutting.

Khan et al. [42] built upon earlier research to indicate that MQL produced the best surface quality over a wide range of compared to both wet and dry machining. As opposed to wet turning, the MQL approach was shown to be superior by Hwang and Lee [43]. In addition, they suggested an optimal configuration of cutting parameters for turning with MQL to improve some of the researchers also investigated the use of Nanofluids in the MQL approach researchers. Cutting tool nose wear and machining temperatures were studied by Rao and Satyanarayana [44] using a carbon nanotube mixed Nanofluid for MQL in a turning operation. “Turning AISI 304L using vegetable-based cutting fluids led Cetin et al.[45] to the conclusion that sunflower and canola as based fluids perform better machining compared to dry or wet operations.”

Compared to dry turning, MQL results in a 40% reduction in cutting force, a 36% reduction in cutting temperature, and a 30% improvement in surface quality, as found by Lohar and Nanavaty [46]. With the use of an MQL system based on supercritical carbon dioxide, Stephenson et al. [47] increased material removal rates and extended tool lifetimes. It was discovered to have a 40% larger impact on the parameter than aqueous fluid. When compared to dry machining, cutting forces are lowered by 17.07% when employing the MQL process, and cooling around the tooltip is enhanced by 6.72 percent, as shown by SainiForl. [48]. As an example, Amrita et al. [49] virtually investigated the potential benefits of using Nano-graphite augmented machining oil in the turning process. “MQL with Nano-graphite fluid was shown to decrease surface unevenness, cutting force significantly, machining temperature, and tool wear compared to wet machining, by

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30%, 54%, 25%, and 71%, respectively." In addition, Sharma et al. [50] have conducted a thorough literature analysis examining how various Nanofluids and traditional cutting fluids do when compared to the MQL approach.

- **Minimum Quantity Lubrication Application in Drilling Processes**

Drilling using cutting fluid is essential because it aids chip removal from the hole and prevents the drill from being. Some academics have looked at how well different drill tool materials function using MQL. Braga et al. [51] examined the efficiency of uncoated and diamond-coated carbide drills when drilling aluminium-silicon alloys while utilizing a minimal amount of lubricant and an abundance of soluble oil as a coolant (A356). They discovered that the diamond-coated drill performed poorly compared to the uncoated K10 drill due to chips becoming stuck in the nose of the tool. It also produced a higher value of feed force. Since coolant of low viscosity may penetrate the cutting zone more readily than coolant of high viscosity, Heinemann et al. [52] found that using MQL with high water content and lower viscosity had a good impact on deep-hole drilling. "After drilling a large number of holes, Tasdelen et al. [53] analyzed the surface quality of the holes and found that MQL (15 millilitres per hour flow rate) drilling produced superior holes in terms of Ra and Rz to the flood drilling method."

Similar conclusions were reached by Bhowmick and Alpas [54] in dry drilling; MQL requires less torque for drilling m than flood and dry drilling magnesium alloy. Moreover, since MQL lowers temperatures, it reduces the creation of built-up edges and the adherence of Mg to the drill. Compared to more standard drilling methods, MQL - fatty acid cooling on the drill tool surface area surrounded by magnesium adhesion shows the lowest percentage. "To investigate the impact of MQL on the drilling process, Rahim and Sasahara [55] conducted tests using palm oil and synthetic ester on Inconel metal 718." They found that when compared to MQL with synthetic ester, the surface quality of items made with palm oil was significantly better. Comparing MQL to dry and wet drilling, it is clear that MQL results in a higher quality surface and longer tool life. After conducting experiments, Meena and Mansori [56] determined that wet drilling caused flank wear of 0.12 mm, medium-quick lubrication (0.25 mm), and dry drilling (0.41 mm).

- **Minimum Quantity Lubrication ApplicationComparedg**

Compared to dry and wet grinding, MQL grinding produces better machining results with less surface damage. This claim is supported by the findings of other researchers whose experimental experiments produced similar findings. "Braga et al. [51] compared the performance of a cutting liquid based on MoS2 nanoparticles under MQL and wet machining to the results obtained using conventional oils (CANMIST, soybean, and paraffin) in a flood cooling environment and concluded that the former method was superior." Adding MoS2 nanoparticles to soybean oil, paraffin oil, or CANMIST oil may increase the wheel's durability by 15%, 35%, or 46% and reduce the grinding force by 9%, 21%, or 27%, respectively. Moreover, it was shown that MQL could produce a high concentration of MoS2 nanoparticles while maintaining a high grinding ratio (G-ratio).

Surface roughness, specific tangential and normal grinding forces, and other metrics were measured and found to be comparable between MQL and wet grinding by MaoCompared When compared to flood grinding, MQL's temperature reduction and tool-force output are almost similar (and in certain circumstances far better).

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With malleable metals, it performs well. However, MQL has its limits regarding difficult-to-cut materials (Barczak et al.) [58]. For medium or high carbon steels like EN31, it has been observed that the temperature recorded by flood lubrication is 20% lower than that with near-dry machining. However, for low-carbon steels, the temperature is like that in flood lubrication at an equal explicit production rate. When dealing with EN8 steel, this method resulted in substantially lower temperatures than wet machining.

For this reason, MQL was proven to be more beneficial for low-carbon materials by Morgan et al. [59]. Using jet MQL grinding of liquid paraffin, palm oil, rapeseed oil, and soybean oil, Zhang et al. [60] performed an experimental study on MoS2 nanoparticles. According to their findings, compared to other oils, palm oil has a lower coefficient of friction (0.37 vs 0.39 for liquid paraffin) and a higher Sp. Grinding Energy (U).

- **Minimum Quantity Lubrication Application in Milling Processes**

In addition, MQL is used in milling operations. In the case of end-milling Titanium Alloy, for instance, Garcia and Ribeiro [61] observed that MQL allowed for improved lubrication and cooling operations. Evidence included decreased cutting power and increased tool durability. As a bonus, Kang et al. [62] noted that MQL use is possible even at higher cutting speed regimes. When cutting AISI D2, they discovered that using MQL led to improved machining performance compared to using flood coolant, provided the right cutting tools were used. However, all tests were conducted with a set MQL flow rate and fixed cutting settings.

Interestingly, owing to the cultural shift requirement, the MQL program's complete deployment on the shop floor remains doubtful. However, certain businesses, particularly large-scale manufacturing, have wholly used this technology to make specific components. According to Filipovic and Stephenson [63], this application has already shown promising benefits for the future.

Brinksmeier et al. [64] milled TiAl6V4 using an uncoated carbide K40 tool. The cutting parameters were as follows: 210 m/min cutting speed, 0.08 mm/rev feed rate, 5 mm axial depth of cut, and 2 mm radial depth of cut. Cutting forces, tool wear, surface quality, and chip formation were analyzed to arrive at these conclusions. The scientists concluded that the MQL application might provide tool life comparable to overhead flood cooling. The outcomes were accomplished by incorporating a 7 percent emulsion into the cutting fluid. It may also benefit from phosphorus supplements, leading to even higher results.

VII. CONCLUSION

In cases when the full potential of dry machining cannot be realized owing to the limitations of the cutting tools, the use of minimum quantity lubrication (MQL) is preferable. Accordingly, the machining performance for a particular workpiece material may be enhanced by using the optimal configuration for MQL and machining variables. When looking for information on improving the MQL application's efficiency, the literature needed help to reach a consensus on the optimal cutting speed range. For the MQL application to function optimally, it has been discovered that the absorption capacity of the materials used in the workpiece plays a crucial role in creating a protective coating. Machined using the MQL program, each workpiece material may have unique features. To that end, creating MQL machining data for a broad range of workpiece materials is necessary. It is possible that enhancing the MQL application is vital for satisfying sustainable development standards. Very little data on sustainability was found in this review. To determine the MQL

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application's place in sustainable development, it is necessary to do an environmental analysis that factors in both the carbon footprint and environmental load.

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