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ANALYSIS ON NANO FLUID BASED MQL MACHINING

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ABSTRACT

The low thermal conductivity and significant chemical reactivity of this material, despite its higher performance, result in subpar machinability and early tool failure. Nano-cutting fluids are used in titanium alloy machining to tackle the heat dissipation difficulty since they have better thermal conductivity values than standard lubricating oils. Various papers were on exhibit to provide attendees a better understanding of the MQL technology for lubricating edible oils using Nano particles.The MQL is a cooling process, in which a very low volume of coolant with excellent thermo-physical properties, is sprayed directly onto the work piece-tool interface. Most of the experimental studies have shown that application of MQL produces surface better than the flood and dry machining. In turning operation, parameters such as cutting speed, depth of cut, feed rate and tool nose radius have great impact on the surface finish. During high speed turning of steel inherently generates high cutting zone temperature. Such high temperature causes dimensional deviation and failure of cutting tools, surface and subsurface micro cracks, corrosion etc. Therefore, with proper selection of the MQL system and the cutting parameters, it is possible for MQL machining with minimum cost and less quantity of coolant to obtain better conditions, in terms of lubricity, tool life, cutting temperature and surface finish. The findings of this study show that MQL with nano fluid can substitute the flood lubrication for better surface finish.

1. INTRODUCTION

In recent times, modern machining industries are trying to achieve high quality, dimensional accuracy, surface finish, high production rate and cost saving along with reduced environmental impact. In the machining process, one of the commonly carried out operations is a turning. It can be carried out on variety of machines like lathe, special purpose machine or CNC machine. The quality of turning is measured in terms of tolerances and roughness of surface. Surface finish is a quality specified by customer for machined parts [1]. There are many parameters that affect surface roughness, but most are difficult to quantify adequately. In turning operation, parameters such as cutting speed, depth of cut, feed rate and tool nose radius have great impact on the surface finish [2]. The turning operation seems very simple; through high speed turning of steel inherently generates high cutting zone temperature. Such high temperature causes dimensional deviation and premature failure of cutting tools. It also impairs the

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surface integrity of the product by inducing tensile residual stresses and surface and subsurface micro cracks in addition to rapid oxidation and corrosion A cooling lubricant is used in turning operation to reduce friction at tool chip and work piece interface. However, in high speed machining, conventional cutting fluid application fails to penetrate the chip tool interface and thus cannot remove heat effectively The lubricant has a strong effect on machined surface quality and tool wear. The costs related to cutting fluid represent a large amount of total machining cost; also cause health of machining operator and correct disposal [4]. However, at present complete elimination of cutting fluid is not possible. An alternative to conventional flood machining is the application of cutting fluids, in very small quantities to the small area where actual machining takes place. This technique is known as minimum quantity lubrication (MQL). In MQL the heat removal can be done and it also provides sufficient lubrication to prevent the generation of heat and reduces environmental impact [5].

2. LITERATURE REVIEW

Liu et.al. [6] In this study, a new type of blended coolant that is suitable for minimum quantity lubrication (MQL) was developed by leveraging the mutual solubility of castor oil and ethanol. The physicochemical properties of the blended coolant and its effects on cutting vibration, surface hardness, surface roughness and tool wear mechanism under different working conditions were studied. Turning experiments on AISI 304 steel under dry cutting, flood cutting, vegetable oil (castor oil) minimum quantity lubrication (VMQL), 95 % ethanol MQL (EMQL), and blended coolant MQL (BMQL) conditions were conducted using a coated carbide tool. Among all the cooling methods tested, the minimum vibration in the axial and radial axis directions occurred in the BMQL, with vibration intensity reductions of 2.46 % and 3.38 %, respectively.

FarajMajeed et.al. [7] Explored a wide range of cooling techniques for hard turning machining continues to be proposed and assessed. In this review, the overall characteristics of cutting tools and stainless steel materials were reviewed in terms of vibration, surface roughness, cutting force, and tool life while using minimum quantity lubrication (MQL) with paraffin-based Nano fluids. Nanoparticles are particularly appealing in MQL due to its remarkable improvement in the cutting conditions. Under aggressive machining conditions, the lubricant media tends to evaporate or disintegrate when in contact with the cutting tool. With the addition of high thermal conductivity nanoparticle additives as cutting fluid, the performance of the MQL technique has improved remarkably. This review exposed that a few work has used MQL with Nano fluid when machining martensitic stainless steel AISI 420 using TiAlN-coated carbide cutting tool.

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Rukmini SrikantRevuru et.al. [8] Wrote a review on the Application of cutting fluids in machining of titanium alloys. He mentioned that the Titanium alloys are widely used in aerospace, biomedical, and other engineering areas due to their superior properties. However, machining of titanium alloys has always been a challenge due to the high temperatures and tool wear rates. Dry machining has a limited range of permissible cutting conditions and is hence not suitable for industrial production. As a solution, flood cooling using cutting fluids is conventionally used to reduce the cutting temperatures. In order to achieve sustainable machining, different strategies for applying the cutting fluids are developed. Some of the prominent methods include minimum quantity lubrication (MQL), minimum quantity cooled lubrication (MQCL), and cryogenic cooling. He finally concluded that MQL certainly improved compared to other methods while cryogenic or super cooled cutting fluid application (MQCL) has been found to be better for specific situations. Use of Nano fluids for titanium is not very popular among other researchers.

Xiufang Bai et.al. [9] Conducted Experimental evaluation of the lubrication performances of different Nano fluids for minimum quantity lubrication (MQL) in milling Ti-6Al-4V. He stated that the author used six types of Nano fluids, namely, Al2O3, SiO2, MoS2, CNTs, SiC, and graphite, were selected. Cottonseed oil was used as the base oil. The lubrication performance was investigated in terms of milling force, surface roughness, and morphology of workpiece surface. Experimental results demonstrated that the Al2O3 nanoparticle obtained the minimal milling force (Fx = 277.5 N, Fy = 88.3 N), followed by the SiO2 nanoparticle (Fx = 283.6 N, Fy = 86.5 N). The surface roughness obtained by the Al2O3 Nano fluid was the minimum (Ra = 0.594 μm), whereas it was the maximum by using minimum quantity lubrication (Ra = 1.772 μm). Spherical Al2O3 and SiO2 nanoparticles improved the lubrication effect of base oil mostly and were more suitable as environment-friendly additives for the base oil compared with the others.

Woo-Yul Kim et.al. [10] Conducted Numerical study of flow and thermal characteristics in titanium alloy milling with hybrid Nano fluid minimum quantity lubrication and cryogenic nitrogen cooling. The flow and heat transfer characteristics in titanium alloy (Ti-6Al-4V) milling with a hybrid Nano fluid minimum quantity lubrication (nMQL) and cryogenic nitrogen lubrication/cooling method is numerically analysed for two different cryogenic spraying conditions of N2 (sensible cooling) and LN2 (latent cooling), and three different nMQL nozzle spray angles of 0˚, 45˚, and 90˚. The volume of fluid (VOF) model is employed to track the interface between each fluid, which is air, N2, and LN2. The discrete phase model (DPM) is used to solve the trajectory and temperature of nMQL droplets. The heat generation occurred during the milling process, and the phase change of the liquid nitrogen is modelled using the user-defined

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functions (UDF) in ANSYS Fluent. The results show that the LN2 spraying condition provides extremely effective cooling of the Ti-6Al-4V workpiece and tungsten carbide (WC) tool in the Ti-6Al-4V milling process.

3. MQL ON DISSIMILARRESOURCES

A brief overview of important work carried out by different researchers on the role of different machining fluids (vegetable oil, mineral oil, chemical oil, nanoparticles-based oil, etc.) in a minimum lubrication environment during various machining operations.

Table 1. MQL on DissimilarResources

Material	**Aluminium**		**Steel**		**Cast**
Process	**Cast Alloy**	**Forged Alloy**	**High-Alloy Steels ,rolling Bearing steel**	**Free-cutting steel, quenched and tempered steel**	**GG20-GGG70**
Drilling	MQL	MQL	MQL	DRY	DRY
Reaming	MQL	MQL	MQL	NIQL	MQL
Milling	DRY	MQL	DRY	DRY	DRY
Thread cutting	MQL	MQL	MQL	NIQL	MQL
Thread rolling	MQL	MQL	MQL	NIQL	MQL
Deep drilling	MQL	MQL	–	MQL	MQL
Turning	MQL/DRY/dry	MQL/dry	DRY	DRY	DRY
Bobbing			DRY	DRY	DRY
Sawing	MQL	MQL	MQL	MQL	MQL
Broaching	–	–	MQL	MQL/DRY	Dry

N.R.Dhar et.al. [11] Conducted experimental investigation on effect of minimum quantity lubrication in machining AISI 1040 steel. The growing demands for high productivity of machining need use of high cutting velocity and feed rate. Such machining inherently produces high cutting temperature, which not only reduces tool life but also impairs the product quality. Application of cutting fluids changes the performance of machining operations because of their lubrication, cooling, and chip flushing functions. But the conventional cutting fluids are not that effective in such high production machining, particularly

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in continuous cutting of materials likes steels. Minimum quantity lubrication (MQL) presents itself as a viable alternative for turning with respect to tool wear, heat dissipation, and machined surface quality. This paper compares the mechanical performance of MQL to completely dry lubrication for the turning of AISI-1040 steel based on experimental measurement of cutting temperature, chip reduction coefficient, cutting forces, tool wears, surface finish, and dimensional deviation. Results indicated that the use of near dry lubrication leads to lower cutting temperature and cutting force, favourable chip–tool interaction, reduced tool wears, surface roughness, and dimensional deviation.

E.A.Rahim et.al. [12] The author studied the potency of MQL palm oil (MQLPO) as a lubricant in the high speed drilling of Ti–6Al–4V. For the comparison, MQL synthetic ester (MQLSE), air blow and flood conditions were selected. Uniform flank wear, micro-chipping, thermal cracking and flaking were the dominant tool failure modes. It was found that MQLSE and MQLPO gave comparable performance with the flood conditions. In addition, MQLPO outperformed MQLSE on the cutting forces, temperature, power and specific cutting energy. This shows that palm oil can be used as a viable alternative to synthetic ester for MQL lubricant.

N.Talib et.al. [13] Displayed the Tribological behaviour of modified jatropha oil by mixing hexagonal boron nitride nanoparticles as a bio-based lubricant for machining processes. An increasing concern on environmental and health problems caused by petroleum-based oil leads to the development of environmentally benign metalworking fluids from crude jatropha oil (CJO). Commonly, CJO is commercially utilized in food industry but in this current work, is selected to be used as a base stock due to its renewability and biodegradability. The results obtained indicated that MJO5-base mixed with 0.5 wt% of hBN nanoparticle provided the best physicochemical properties due to lowest thermal expansion coefficient of hBN nanoparticles. High formation of TMP triester in MJO5 formed a strong lubrication film which significantly affected the lubrication and tribological behaviour. MJO5 sample exhibited better friction and wear behaviour by 75% and 20% reduction, respectively, especially when compared to SE.

Kim et.al. [14] Conducted Numerical Analysis of Thermal Characteristics of a Milling Process of Titanium Alloy Using Nano fluid Minimum-Quantity Lubrication. The computational fluid dynamics (CFD) approach is introduced for establishing the numerical model for the Nano fluid MQL milling process, and estimated temperatures for pure MQL and for Nano fluid MQL using both hexagonal boron nitride (hBN) and Nano diamond particles are compared with the temperatures measured by thermocouples in the titanium alloy workpiece. The estimated workpiece temperatures are similar to experimental ones, and the model is validated.

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Alborz Shokrani et.al. [15] In this study, a new hybrid cryogenic MQL cooling/lubrication technique is proposed for end milling Ti-6Al-4V using coated solid carbide tools. The effect of the proposed system on machinability of Ti-6Al-4V was studied at various cutting speeds and compared with flood, minimum quantity lubrication (MQL) and cryogenic cooling. Tool life, tool wear and surface roughness were thoroughly investigated as key machinability metrices and a new model for tool life based on tool wear is proposed. The analysis indicates a significant shift in CNC milling performance, as the new hybrid cryogenic MQL technique shows an increased tool life of 30 times is achieved together with a 50% improvement in productivity compared to state-of-the-art flood coolant machining.

Rukmini SrikantRevuru et.al. [16] Conducted the performance evaluation of Nano cutting fluids in minimum quantity lubrication & developed a finite element model. Two different solid lubricants — boric acid and molybdenum disulphide were dispersed in the coconut oil. Different machining parameters like cutting forces, cutting temperatures and surface roughness were studied while applying the formulated fluids in MQL. After observing the superior performance of Nano fluids at the given cutting conditions, a finite element based model has been developed to predict forces and cutting temperatures. The model was compared with the experimental values and found capable of predicting the values within 8% accuracy. The validated model was used to predict the values for other cases.

Guangyuan Zhu et.al. [17] Conducted Numerical and experimental optimizations of nozzle distance in minimum quantity lubrication (MQL) milling process. Minimum quantity lubrication (MQL) is the efficient and environmentally friendly technology, which is desirable to achieve sustainability during machining process. A two-way computational method has been employed to solve for the comprehensive flow field and particle trajectories, with the wall condition established on the spray impingement theory. The interactions of air flow rates and spindle rotational speeds on droplet penetration are investigated in details. The comparison between numerical simulations and milling experiments has shown great consistency. This paper has achieved better understanding of the nozzle orientation setup and device development in MQL milling process, especially for external MQL.

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4. ECO FRIENDLY CUTTING FLUIDS IN MQL

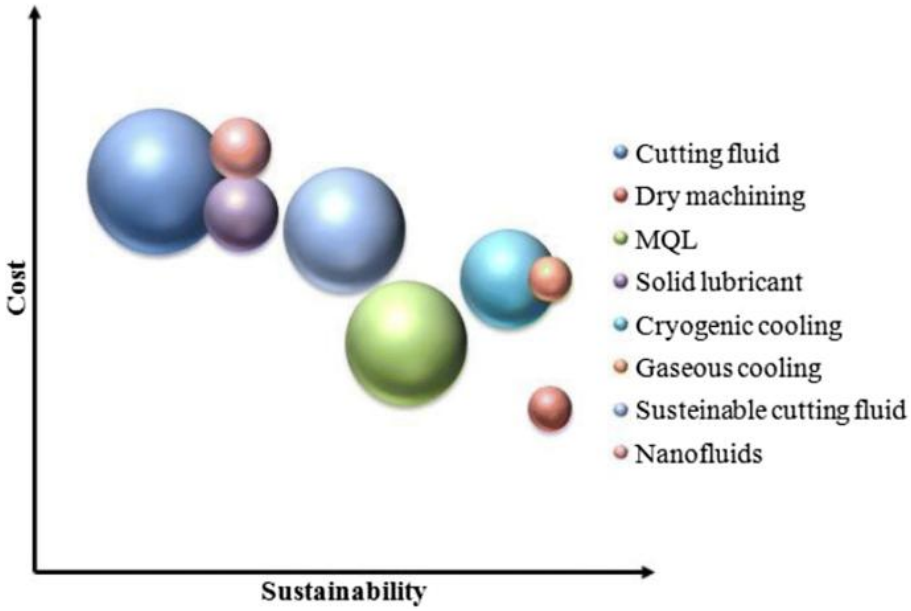

Fig 1. Sustainability Vs Cost for different cutting fluids

MQL technology drastically reduces the utilization of cutting fluids in machining operation. Biodegradability is the main reason for selecting vegetable oil as MQL base fluid. The synthetic ester present in vegetable oil possesses high biodegradability.

Main Functions of Cutting Fluids

1. **Lubrication at low speeds**

   At low cutting speeds, cooling is not very important, while lubrication is important to reduce friction and avoid the formation of built-up-edge. In this case, an oil based fluid must be used. At high cutting speeds, the conditions are not favourable to fluid penetration, to reach the interface and work as a lubricant.

2. **Cooling at high cutting speeds**

   As coolers, cutting fluids decrease cutting temperature through the heat dissipation (cooling) The cutting fluid ability of sweeping the chips away from the cutting zone depends on its viscosity and its volume flow, besides, of course, the kind of machining operation and chip type formed.

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Cooling Ability of Nano Fluids

Aiming to classify the main cutting fluids based on their cooling ability, Sales (1999) developed a methodology which consisted in heating a standard workpiece and monitoring the cooling curve of it. This workpiece was fixed to the clutch of a lathe jigs and rotated at 150 rpm and its temperature was measured using an infrared sensor. The data acquisition started when the workpiece temperature reached 300°C and the measurement continued up to room temperature. Emulsions and synthetic fluids were applied using a concentration of 5%.

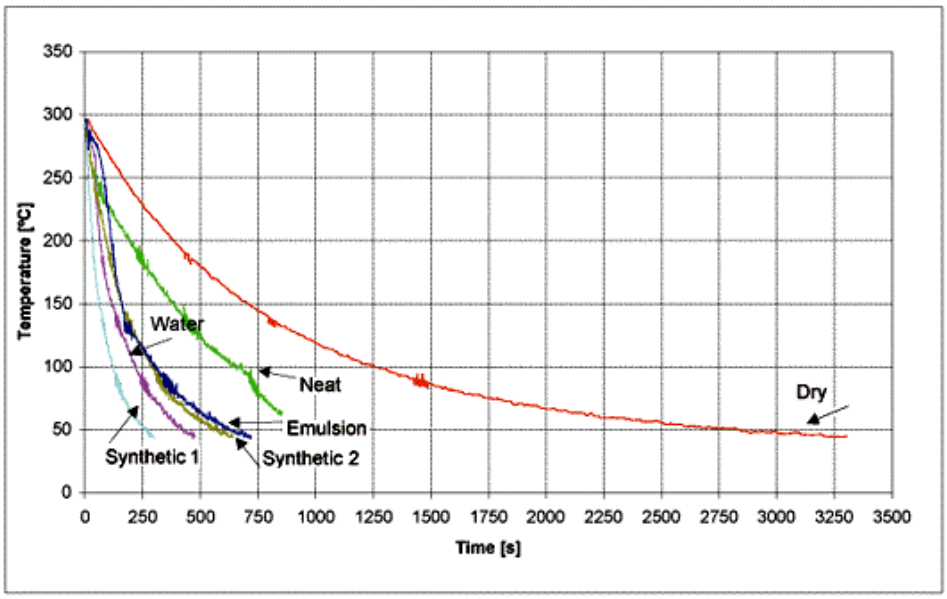

Fig 2. Cooling Curves of all fluids

Experiments with emulsions and synthetic fluids at 10% concentration presented similar results, what confirmed the higher cooling ability of synthetic oil 1 compared with the other fluids experimented. Based on the cooling curves, the convection coefficients of the fluids, h, were calculated and shown on Figure 3.

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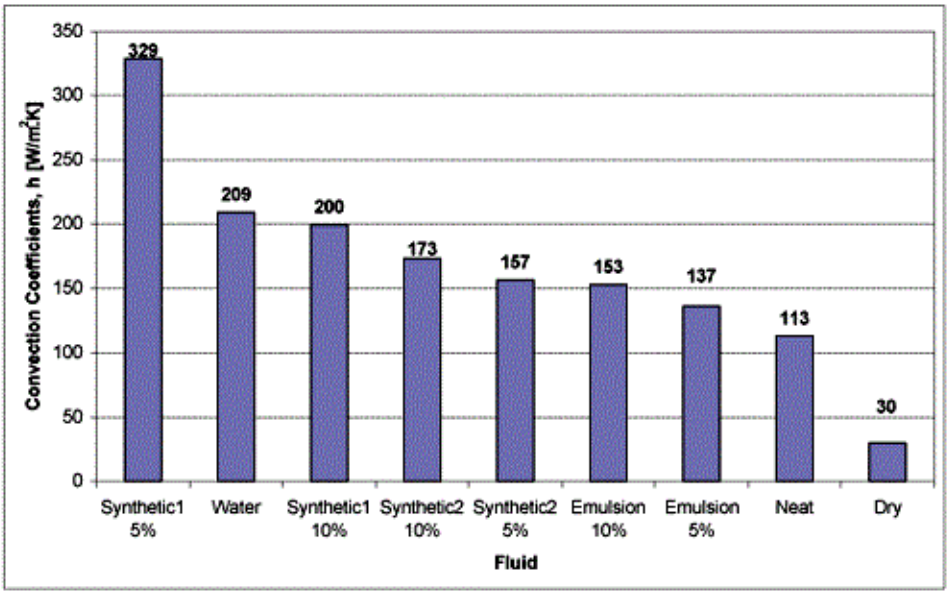

Fig 3. Convection Coefficients of Cutting Fluids

In machining processes, a fluid that removes a larger amount of heat, may promote a reduction in the softening effect of the workpiece material caused by the heat. With this, the metal keeps its resistance at higher levels than when a cutting fluid with lower cooling ability is used. Figure 4 shows that the higher the temperatures (or cutting speeds) more pronounced is this effect. For cutting speed of 244 m/min, the temperatures when the fluids with the highest cooling ability are used.

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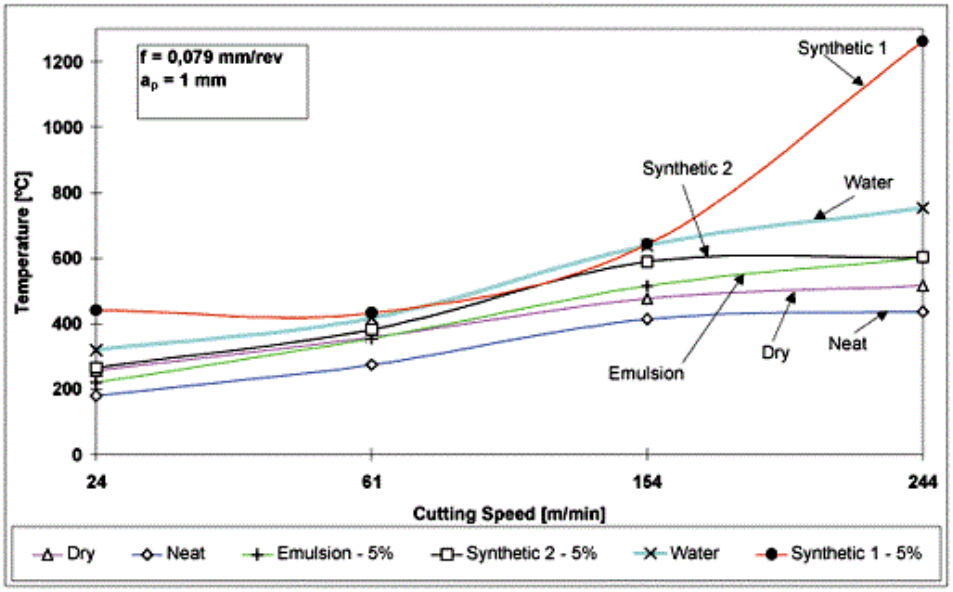

Fig 4. Chip tool interference with different cutting fluids

CONNCLUSION

It is seen that different researchers have proposed different coolant and cooling systems such as conventional flood system, jet spray system, near dry system, MQL system etc. for machining. The conventional flood systems are practically accepted by the metal cutting industries. However, it has certain inherent disadvantages such as unaffordable cost, the requirement of skilled manpower, limited turning performance. On this background, MQL with nano fluid cooling technique is more suitable for the low volume and better turning characteristics. There is a scope for use of MQL with nano fluid in metal cutting industries during machining operation to improve the turning characteristics.

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