Characteristics of Various Nano-Fluids Used in Minimum Quantity Lubrication in Grinding

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ABSTRACT

Grinding is a material removal and surface finish process used to produce and finish components composed of metals and other materials. The conventional cutting fluids used in grinding processes represent extreme environmental risk. The disposal or reprocessing of these lethal fluids is expensive and the contamination on the proximities of the machines may trigger risks to the health of personnel on the manufacturing floor. The review is based on the experimental evaluation of the grinding of super alloy GH4169. This review aims to explore the concept of minimum quantity lubrication (MQL) in the grinding process and also the characteristics of various nano-fluids used in MQL In this work nanoparticles exhibiting different physiochemical properties are used. Characteristics and properties of the nanoparticles in nano-fluids are examined using grinding characterizations which are grinding forces, sliding friction coefficient, specific sliding grinding energy, grinding ratio. The comparative study of various properties of nano-particles is shown using graphical representation of various characterizations and nanoparticles. Analysis and the final conclusions are based on the results obtained by thoroughly studying and analyzing the affecting parameters, grinding characterizations. The practical applications are also reviewed with the futuristic scope and development in the topic. The review revolves around the comparison of nanoparticles which are ZrO_2,CNTs,ND,MoS_2,SiO_2,and Al2O3.

Keywords*: Grinding, Cutting Fluids, MQL (Minimum Quantity Lubrication), Nanofluids.*

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1. INTRODUCTION:

Grinding consists of an abrasive product, generally a rotating wheel brought into the contact with a work surface. The grinding wheel is comprises of abrasive grains held together in a binder. These grains act as cutting tools, removing small chips of material from the work. As these irregular grains wear and become dull, the added resistance leads to fracture of the grains or weakening of their bond. Grinding has higher machining precision than other similar processes. [3]

Minimum quantity lubrication (MQL) technique is a green processing method.[1] Dry machining and machining with Minimum Quantity of Lubricant (MQL) have been calling the attention of researchers and technicians in the machining area as an alternative to traditional fluids.[2] The MQL system is based on the residue-free cutting oil usage principle, with a low flow of cutting fluid, which one is mixed with compressed air and utilized in high pressures. The lubricating function is conditioned by the oil and the cooling function by the compressed air. This small quantity of oil (usually < 100mL/h) is sufficient to reduce the friction in the cutting, as in conventional fluid (mixture of oil and water). Considering high costs of conventional cutting fluids and environmental harm caused by them, MQL is preferred. The MQL system has become increasingly relevant in the last decade. To develop a more advanced processing method using lubricants with less energy consumption and less environmental pollution, nanoparticles are employed as additives of nanofluids to significantly improve the lubrication effect and heat transfer. Nanofluids are colloidal mixtures. They consist of nanometer-sized particles (1 nm to 100 nm) in a base fluid. They can be classified as metallic (Fe, Cu, Ag), non-metallic (diamond/ ND), oxide (Al_2O_3, SiO_2, ZrO_2), carbide (carbon nanotubes), sulfide (MoS_2), ceramic, and hybrid. Nanofluids demonstrate many advantages, including superior lubrication performance and thermal conductivity [4]. The authors found that with the addition of nanoparticles to conventional lubricants, the lubrication properties can be significantly improved. Given the unique physical properties, different nanoparticles will exhibit various lubrication effects. Thus, the present work discusses grinding GH4169 with six different types of nano-fluids and pure palm oil by using the MQL technique. Experimental evaluations are conducted on the lubrication property of the grinding wheel/workpiece interface in terms of sliding grinding force, specific sliding grinding energy, G ratio, and surface quality under different lubrication conditions. Overall, this review aims to determine which kinds of nano-fluids demonstrate superior lubrication performance.

2. BASE OILS AND ADDITIVES:

2.1 Base Oils:

- Mineral Oils
- Hydrocracked Base Oils
- Synthetic Oils
- Vegetable Oils
- Bio-Based Lubricant Fluids

Cutting oils are normally composed of base oils and additives. Base oils are essentially the main ingredients in lubricants, accounting for over 95% of lubricant.There are several kinds of base oils such as mineral, synthetic, and vegetable oils which can be used in the formulation of machining lubricants. The most common base oils are those derived from petroleum crude oil, for instance mineral base oils that consist of hydrocarbons with paraffinic, naphthenic, or aromatic structures.

Lubricants based on mineral oils have been used in many kinds of applications including automotive engines, hydraulic systems, industrial gears, as well as in machining applications. The major advantage of mineral base oils is their low cost. However, from an environmental point of view, mineral base oils are not readily biodegradable. Conventional mineral oils normally include impurities such as aromatic, polar, and nitrogen containing compounds. These oils show moderate oxidative resistance because under moderate to high temperatures many of their thermally unstable compounds become volatilized and oxidized. Mineral base oils have higher levels of purity, higher proportions of saturates (>90%), lower aromatic content, higher flash point, higher viscosity index (V.I.) and higher thermal stability than conventional mineral base stocks.

Hydrocracking is defined as catalytic cracking and hydrogenation at high pressure and relative high temperature, wherein heavier feedstock is converted into lighter (more desirable) products in the presence of hydrogen and special catalysts. Hydrocracked base oils have low toxicity, due to the reduction of impurities.Hydrocracked base oils are clear and colorless, and more biodegradable (up to 80%) compared to mineral oils.

Synthetic base oils obtained by chemical synthesis are the latest base oils being developed, with superior physical, chemical and biodegradability properties. Poly-alpha-olefins (PAOs), polyalkylene glycols (PAGs), esters, and silicones are typical types of synthetic base oils. Theyexhibit excellent oxidative stability, high-temperature stability, very low pour points, extremely high viscosity index (VI), high-pressure stability, high hydrolytic stability, low toxicity, good biodegradability (up to 80%), low affinity to evaporation, low-temperature fluidity, and low flammability.They are synthesized, rather than extracted and modified, making them more pure.

Vegetable or plant oils are triglycerides of natural fatty acids and have higher levels of biodegradability and inferior toxicity than mineral or synthetic oils. Such base oils are extracted from plants like rapeseed, castor, canola, soybean, sunflower, palm, olive, and coconut. Vegetable base oils in general have appropriate properties such as high viscosity index (VI), high lubricity, high shear stability, high flash point, low volatility, high detergency and good dispersancy properties. Lubricants based on vegetable oils are approximately twice more expensive than conventional mineral oils and have lower cost than synthetic oils.

2.2 Additives:

- Extreme Pressure additives
- Anti-Wear Additives
- Nanofluids

Additives are chemical compounds comprising up to 5% of the weight of cutting oils, which improve the oils' lubrication performance. Additives provide lower friction and wear, higher viscosity, improved viscosity index, resistance to corrosion, and oxidative stability. The most important additives in metal cutting fluids are extreme pressure (EP) agents, anti-wear (AW) additives, friction modifiers (FM), viscosity modifiers, corrosion inhibitors and antioxidants. EP and AW additives either adsorb or react with the work surface to reduce friction by forming a boundary lubricant film. The application of such additives in cutting fluids leads to improved machining performance including higher surface quality, higher tool life, lower machining force as well as lower specific energy.

Different nanoparticles exhibit various physicochemical properties (e.g., structure and shape), which can influence their lubricating properties. In this work, six nano-fluids, namely, MoS_2, SiO_2, diamond, carbon nanotubes (CNTs), Al_2O_3, and ZrO_2, were used as minimum quantity lubrication grinding fluids to select the kind of nanoparticles with optimum lubrication performance in grinding nickel alloy GH4169.

3. GRINDING CHARACTERIZATIONS:

3.1 Grinding Force:

Malkin et al. [5] believed that the grinding force and specific grinding energy are generated by two components: cutting and sliding. The grinding force is generally represented by tangential grinding force (F_t) and normal grinding force (F_n). The tangential grinding force (F_t) comprises tangential cutting force ($F_{t,c}$) and tangential sliding force ($F_{t,sl}$). The normal grinding force (F_n) comprises normal cutting force ($F_{n.c}$) and normal sliding force ($F_{n,sl}$). The cutting forces (($F_{t,c}$), ($F_{n,c}$)) are constant. Therefore, the sliding force (($F_{t,sl}$), ($F_{n,sl}$)) is a variable. When the lubrication state changes, the sliding force will change accordingly, and the tangential grinding force and specific grinding energy will change proportionally.

3.2 Specific Sliding Grinding Energy (U_{sl}):

The specific grinding energy refers to the energy needed to remove a unit volume of materials. In the process, lower specific grinding energy indicates higher workpiece machining efficiency. The specificsliding grinding energy is calculated from the tangential sliding force [6].

3.3 Sliding Friction Coefficient (μ_{sl}):

The sliding friction coefficient is the ratio of the tangential sliding force ($F_{t,sl}$) to the normal sliding force ($F_{n,sl}$). The sliding friction coefficient neglects the effect of the cutting force (constant) but involves the sliding force, thus enabling to reflect accurately the lubrication effect of the grinding wheel/workpiece interface under different lubrication conditions [6].

3.4 Grinding Ratio (G-ratio):

G-ratio is defined as the volume of material removal (V_w) per unit volume of grinding wheel wear (V_s). The measurement method of the grinding wheel wear was adopted as described in the reference [7]. Under the same grinding conditions, the G-ratio shows the lubrication effects of the grinding wheel/workpiece interface, and high G-ratio reflects the lighter grinding wheel wear extent. Furthermore, the service life of the grinding wheel can be improved correspondingly.

4.PROPERTIES OF NANO-FLUIDS:

Nanoparticles exhibit small size but with high specific area and surface binding energy, as well as numerous atoms on the surface. Nano-fluid is adsorbed onto the workpiece and grinding wheel surface more tightly, which manifested a better lubrication effect.

- Al_2O_3 nanoparticles are spherical with characteristics of high strength, hardness, and heat resistance and reduce the sliding friction coefficient and shear stress during the abrasive process.
- The SiO_2 nanoparticles are spherical, and the surface molecules exhibit a 3D network structure. The SiO_2 nanoparticles in the base oil demonstrate extremely high diffusivity and self-diffusion capability. The elements in some SiO_2 nanoparticles may even diffuse and penetrate into workpiece surface or sub-surface and the matrix to form solid solutions. "Third body" effect prevents direct contact between abrasive grains and the workpiece friction pair, thus reducing the friction loss.
- The MoS_2 nanoparticles are ellipsoidal, weak. During the grinding process, a plane of low shearing force will be generated because of the strong Mo-S binding. Furthermore, this plane will be broken along the molecular layer upon shearing force between molecules, forming a glide plane. When a grinding force was loaded, the MoS_2 nanoparticles will extend into thin physical films in the grinding area, reducing friction and wear [8].
- CNTs are coaxial circular tubes composed by layers and dozens of layers of carbon atoms in hexagonal arrangement. It cannot produce effective rolling like spherical nanoparticles and serve as “micro-bearings” because of its cylinder structure with easy agglomeration. Therefore, this phenomenon can only produce limited antifriction effect.
- The ZrO_2 nanoparticles are mainly spherical.Nanoparticles will concentrate on the workpiece surface defect, thus establishing a layer of self-healing lubrication film on the friction pair surface and achieving good lubrication effect.

5.

Experiment No.	Grinding fluid	Lubricating Condition
1	Water-solute grinding liquid (5 vol%)	Flood
2	Pure palm oil	MQL
3	MoS_2 - palm oil (6 wt.%)	MQL
4	SiO_2 - palm oil (6 wt.%)	MQL
5	ND - palm oil (6 wt.%)	MQL
6	CNTs - palm oil (6 wt.%)	MQL
7	Al_2O_3 - palm oil (6 wt.%)	MQL
8	ZrO_2 - palm oil (6 wt.%)	MQL

Table -1: Experimental design for the lubrication effect comparison of different grinding fluids.

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RESULTS:

5.1 Grinding forces:

As shown in Fig.1, the sliding grinding forces increased with an increased number of passes in both normal and tangential directions.The sliding grinding force under nanofluid (particularly Al_2O_3 and MoS_2) MQL is even lower. Pure palm oil MQL achieves smaller sliding grinding force.Hence nanofluid is superior to pure palm oil in lubrication improvement.

5.2 Sliding Friction Coefficient:

As shown in Fig.2, The flood lubrication showed the highest value. The pure palm oil MQL significantly improves the lubrication performance, and the sliding friction coefficient decreases. The nanofluids (ZrO_2, ND, and CNTs) achieved slightly lower sliding friction coefficient than that of pure palm oil MQL. MoS_2, SiO_2, and Al_2O_3 nanofluids further reduced in sliding friction coefficient values.

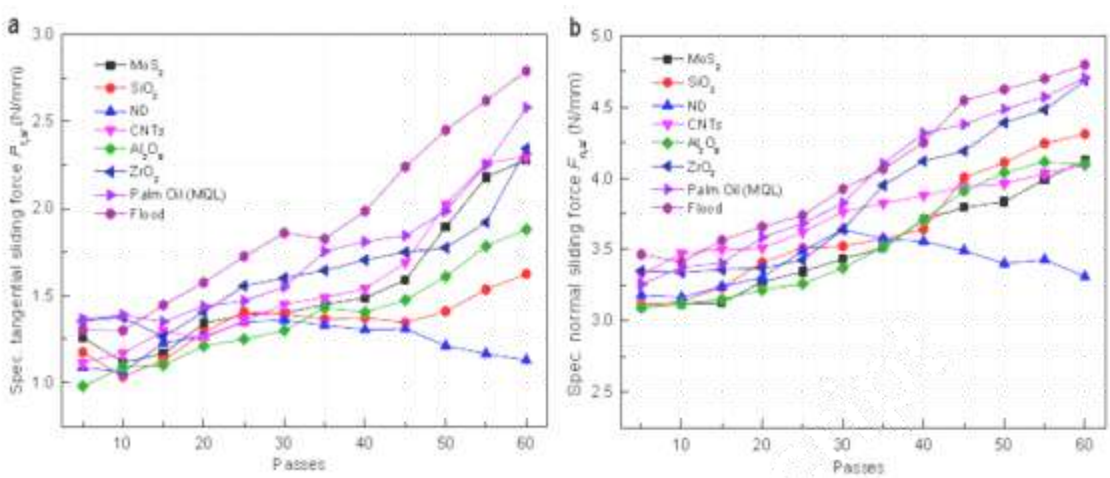

Fig-1: Graph of No. of Passes Vs. Grinding Forces

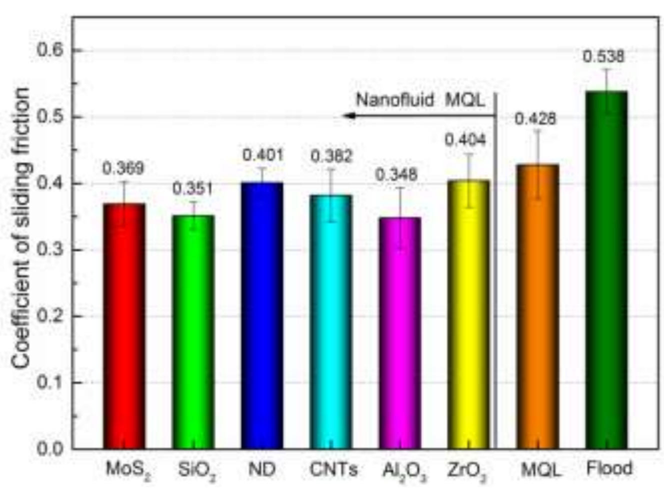

Fig -2: Coefficient of Sliding Friction

5.3Specific Sliding Grinding Energy:

Compared with flood lubrication, pure palm oil MQL slightly reduced in specific sliding grinding energy, the nanofluid MQL showed further reduction. As shown in Fig.3, The specific sliding grinding energy of MoS_2, Al_2O_3, and SiO_2 nanofluids decreased. MoS_2 nanoparticles achieved the optimum lubrication performance, followed by diamond nanoparticles with soybean oil-based nanofluids (MoS_2, ZrO_2, and ND) for MQL grinding.

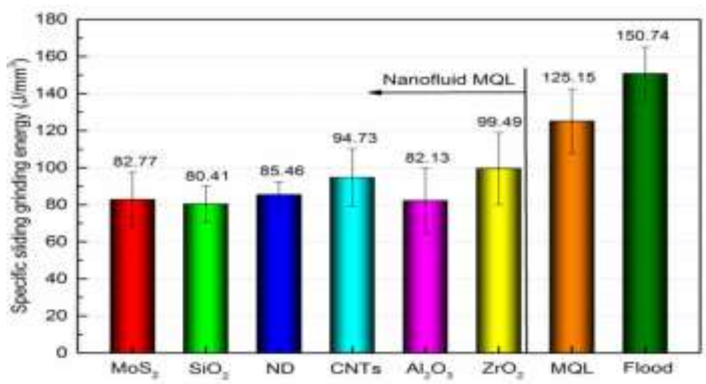

Fig-3: Specific sliding grinding energy

5.4 Grinding Ratio:

As shown in Fig.4, The least G-ratio values were observed in flood lubrication. The G-ratio of pure palm oil MQL was slightly higher and that of nanofluid MQL was significantly higher than in flood lubrication. The nanoparticles showed better anti-wear characteristic of the grinding wheel than pure palm oil.

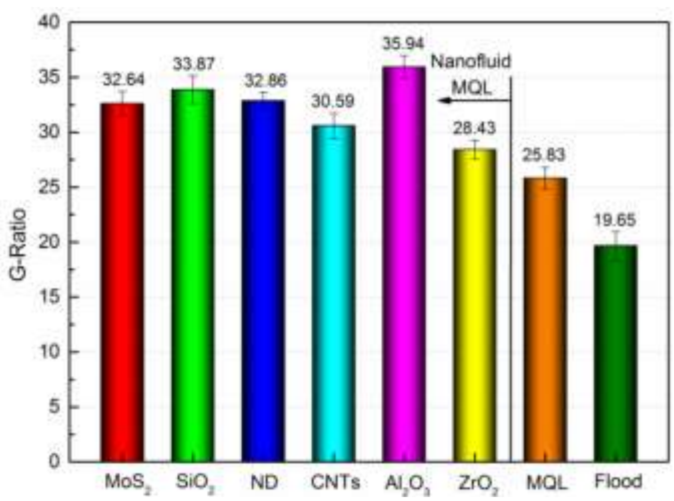

Fig-4: G-Ratio

6. CONCLUSION:

- Properties of conventional cutting fluids used in grinding are not as preferable as MQL nanofluids. Also they are hazardous for environment and even they are costlier than MQL.

- Lubrication properties of both conventional cutting fluid and MQL Nanofluids were studied in this work. Various characteristics were studied in this work viz sliding grinding force, sliding friction coefficient, specific sliding grinding energy, G-ratio.
- The grinding force reduction in the nanofluid MQL were more significant. The nanofluid MQL presented best and flood lubrication presented the worst lubrication properties.
- The Al_2O_3 nanofluid obtained the lowest sliding friction coefficient and specific sliding grinding energy but achieved the highest G-ratio.
- The lubrication properties of the six kinds of nanofluids can be described in the following order:
  ZrO_2 < CNTs < ND < MoS_2< SiO_2< Al_2O_3.
- Among these compounds, Al_2O_3, MoS_2, and SiO_2 nanoparticles are more appropriate as additives for nanofluids.

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