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An overview on performance of metal working fluids with enrichment of nanoparticles for machining process

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Abstract. Tool wear is natural phenomenon, and this leads to tool failure which is caused mainly due to various aspects like the surface of the work piece, material of the work piece to be machined and other. The application of the metal working fluids (MWF's) (or generally coolant) is considered to reduce the friction between the work and tool and to provide lubrication as well as cooling. In a machining process, the use of coolant is essential to dissipate the heat generated and to enhance various properties like productivity, tool life, machinability, etc. There are many types of oil based MWF's are available like mineral oil, semi-synthetic oil, synthetic oil based MWF's. But lately vegetable oil based MWF's are being used because of its eco-friendly nature. Recently Nanoparticles are used to enhance the properties of metal working fluids. In this paper there is brief explanation on preparation of metal working fluids with enrichment of Nanoparticles.

Keywords: Tool wear, Eco-friendly, Metal working Fluids, Nano Additives

1. Introduction
Machining is a process of material removal in which the loss of material is caused by affecting a relative motion between tool and work piece. Due to removal of material in the form of chips, new surfaces are cleaved from the work piece accompanied by a large consumption of energy. The mechanical energy necessary for the machining operation is transformed into heat, leading to conditions of high pressure, high temperatures and severe thermal and frictional conditions, consequently making metal cutting process more and more inefficient in terms of tool life, dimensional accuracy and material removal rate.

To avoid difficulties in machining an effective coolant system is to be provided using a cutting fluid. The important functions of cutting fluids are cooling the tool and workpiece, lubricating chip, tool and workpiece and improve surface finish [1]. The main requirements of a cutting fluid are 1. Long life, 2.Should not form oxides, 3. Good thermal conductivity, 4.Less wetability, 5.Less odour, 6. Should not be flammable, 7.Should not affect the health of workers [1].

In manufacturing industry, many types of lubricants are used as a baseoil for metal working fluids. The fluids which are mainly used as base oil are water, distilled water, mineral oil, synthetic oil, vegetable oil, etc. Base oils cannot be used directly, since pure or raw base oil may cause corrosion, and some can be chemically imbalanced and cannot have a long-life period. So, additives are added to the base oil for better performance. Based on the substance that is used as base oil, additives changes. Additives are chemical substances that are used to enhance the properties of the base oil and improve the performance by taking out negative properties form the base oil. Additives may function as anti-wear, anti-corrosive, anti-oxidant and neutralizing agents and some can be anti-bacterial (mainly for vegetable oils). Simply additives are added to make base oil chemically stable and to become more user friendly to use.

Recently vegetable oils are widely used because of its high flash points and biodegradability when compared to the mineral oils[2], but vegetable oils contain unsaturated fatty acids which poses some problems in terms of corrosiveness and life of the coolant oil, because of high temperature raise in machining process [2].So, vegetable oils are hydrolysed to get ester oil compound which has more stability due to the presence of ester compound[3]. Additives are to this ester compound of their respective vegetable base oil. Lawal et al. [4] intensive research work on the formulation of vegetable based metal working fluids using appropriate additives like Zinc diamydithiocarbamate (ZDDC), Zinc dialkyldithio phosphate (ZDDP), etc. Lawal et al. also reported about various emulsifiers and surfactants used in preparation of the vegetable based oils, and then they compared the properties like surface roughness, tool wear between rapeseed, coconut, sunflower oil based metal working fluids and every result is compared with the commercial vegetable based oil and commercial mineral oil. And the paper concluded that vegetable based oil gave better performance than mineral oil and it is reported that surface roughness and tool wear is improved when coconut oil is used compared to the soluble oil. Commercial vegetable based cutting fluids are used extensively, because of its good properties and high efficient performance.

In this study it is discussed about process of preparation of MWF's with enrichment of nanoparticles.

2. Performance of MWF's with enrichment of nanoparticles

Nowadays nanoparticles are extensively used in many fields, in the field of manufacturing industry it is used to enhance the properties of MWF's. The most commonly used Nano particles are

1. Molybdenum disulphide (MoS_2)
2. Multi walled carbon Nano tubes (MWCNT)
3. Single walled carbon Nano tubes (SWCNT)
4. Aluminium oxide (Al_2O_3)
5. Titanium dioxide (TiO_2)
6. Copper oxide (CuO)
7. Silicon dioxide(SiO_2)
8. Zirconium dioxide (ZrO_2)
9. Hexagonal boron nitride (hBN)
10. Graphite Nanoplatelets (GnP)
11. Nano boric acid (NBA)
12. Nano diamond (ND)

Based on the literature study of Rabesh et al. [5], Nanofluids shown better rheological, tribological properties and thermal conductivity is increased. It is also reported that surface finish is increased because of Nanoparticles. Rabesh et al. suggested of hybrid Nanofluids which contains two or more Nanoparticles. Since Nanoparticles give a prominent change and increase in the properties of the metal working fluid, so it is used widely in all machining applications as coolant oil such as turning, milling, drilling and grinding in both CNC and lathe operations. The following study is based on the various works on different "machining applications" with different Nanoparticles and various base oils.

2.1. Turning process

Srikant et al. [6] experimented on mixing of copper oxide (CuO) in water which acts as base oil. It is reported that the CuO particles are mixed in proportions 0.5-8 vol% with 0.5 as equal interval. Finally, it is concluded that water based cutting fluid with CuO particles given good results in maintaining temperature which in turn results in increase of tool life.

Krishna et al. [7] experimented on mixing of Nano Boric acid in proportions 0.25, 0.5-8 wt% to SAE-40 oil and coconut oil, and it is reported that 0.5% of Nano Boric Acid reduced overall temperature compared to the other experiments carried out on different wt%, Taguchi method is used for design of experiments. It is also reported that the Nanoparticles have enhanced the oil properties greatly and given better surface finish and decreased great amount of temperature.

Amrita et al. [8] experimented on mixing of Nano Graphite (size < 80nm) in coconut oil in proportions 0.1, 0.3, 0.5 wt%. It is reported that they used MQL (minimal quantity lubrication) technique at different flow rates 10 and 15 ml/min and obtained good results in reducing temperature and cutting forces at the flow rate of 15 ml/min. They used Taguchi loss method for design of experiments for setting optimal parameters.

Sayuti et al. [9] experimented on mixing of silicon dioxide (SiO_2) which has size of 5-15nm in mineral oil. The proportions added were 0.2, 0.5 and 1 wt% and in this study Sayuti et al. shown better results in good surface finish and least tool wear at 0.5 wt% of Nanoparticle.

Gupta et al. [10] experimented on mixing of Al_2O_3, MoS_2 and Graphite in vegetable oil separately. All the Nanoparticles are mixed at 3 wt%. It is reported that comparing Al_2O_3, MoS_2 and graphite based vegetable oil due to good thermal conductivity graphite based vegetable oil given better performance than the other two in reducing overall temperature, but MoS_2 gave better surface finish.

Raju et al. [11] experimented on mixing of Multiwalled carbon Nanotubes (MWCNT) (size 10-20nm) in "distilled water" at a proportion of 0.2 vol%. In this paper it is reported that with the use of distilled water based fluid mixed with 0.2 vol% MWCNT cutting forces and surface roughness reduces 5-8% and 9-22%, respectively when compared to dry and base fluid.

Pavani et al. [12] experimented on mixing of Nano Boric Acid in "soybean oil" and "coconut oil". It is mentioned that the mixing is done with the use of "mechanical stirrer". Taguchi method is used to design the experiment. It was found that 2% wt of Nano Boric Acid is optimum for soybean oil and 3% wt for coconut oil. In this paper the comparison is made between tip temperature of the tungsten carbide (WC) tools, surface roughness and cutting forces. It is concluded that the vegetable based oils with enrichment of Nano Boric Acid given good results. Cutting temperatures reduced and surface finish increased to a maximum level compared with dry machining. It is also concluded that the study encourages to the use of vegetable based oil.

Su et al. [13] experimented on mixing of Nano Graphite (size 35nm) in "LB2000 vegetable based commercial cutting fluid" and "PriEco6000 unsaturated polyol ester oil". The proportions are 0.1 and 0.5%. Nanofluids are formulated in two-step method. Ultrasonication is used for mixing and it is done at 40KHz, 100W. It is reported that irrespective of cutting oil both graphite-based Nanofluids reduced cutting forces and a good amount of temperature. But LB2000 given maximum reduction in temperature when compared to dry cutting.

Amrita et al. [14] experimented on mixing of Functionalized Nano Graphite (FNG, size 80nm), Nano Boric Acid (NBA, size 100nm) and $nMoS_2$ (size 100nm) in water-miscible oil, at a definite proportion of 0.3 wt%. In the series of experiments $nMoS_2$ Nanoparticles at 0.3 wt% recorded reduction in cutting forces and recorded good wear and surface properties. But in terms of heat dissipation NBA at 0.3 wt% shown good improvement when compared other coolant conditions.

2.2. Drilling process

Chatha et al. [15] experimented on Soyabean oil as a base oil and taking Al_2O_3 1.5vol% in Drilling process, the size of the Nanoparticle is taken approximately 20nm. In this study, it has given difference between dry and wet drilling conditions by using MQL technique. In this, he has found out that by the application of the Nano particles no. of drilled holes increases which means that the life of the tool has been increased when compared with the dry conditions.

Chai et al. [16] experimented by taking hydrogenated oil as a base oil and Multi walled carbon Nano particles (MWCNT) in different proportions like 22, 50, 100ppm.This means that he has taken a very smaller ratio of MWCNT. The size of MWCNT is in between 10-12nm. The process used for experimentation is drilling process. As the volume percentage is very low then we can tell the quantity in terms of parts per million(ppm). It has been observed that the thermal conductivity of the base oil (hydrogenated oil) is increased with addition of MWCNT.

Nam et al. [17] experimented by taking vegetable oil and paraffin oils as base fluids and Nano diamond (ND) as Nano particle in Drilling process. Size of particle is 30nm. ND is taken in 1,2vol%. With the addition of 1% in paraffin oil gives more improvement in reducing thrust forces, tool wear than by adding 2% in vegetable oil. Nano diamond plays an important role in reducing the tool wear, but the only limitation is its high cost.

2.3. Grinding process

Prabhu and Vinayagam. [18] experimented by taking SAE20W40 oil and MWCNT and CNT (Carbon Nano tubes) in Grinding process. The size is 10-12nm for MWCNT and 1-2nm for CNT. Initially they have taken 0.2vol% of MWCNT and observed that there is slight improvement in surface quality from micro level to Nano level. After that, by taking 2vol% of MWCNT, there is an increase in flash and fire point of the Nano cutting fluid. By taking CNT it us observed that there is an improvement in the surface roughness value of the workpiece.

Kalita et al. [19] experimented Soyabean oil as a base oil and MoS_2 with 5, 20wt% in Grinding process. The size of Nanoparticle is less than100nm. By using MQL technique the cutting fluid produces lesser coefficient of friction and improves the grinding forces without effecting the material removal rate, and wheel wear reduces.

Mao et al. [20] experimented by taking deionized water and canola oil and their respective Nano particles Al_2O_3 and MoS_2 in Grinding process. Size of Al_2O_3 is 40, 80nm and size of MoS_2 is 70nm. When Al_2O_3 in added in deionized water and MoS_2 in canola oil it is observed that higher concentration of Nanoparticles reduces grinding forces and temperature and it depends upon the oil that will be chosen.

3. Conclusion

As discussed above Nanoparticles increase the properties of metal working fluids, based on the above study the Nanoparticles used for the enrichment of metal working fluids for machining are Multiwalled Carbon Nano Tubes (MWCNT), Molybdenum disulfide (MoS_2, $nMoS_2$), Nano Graphite, Aluminium oxide (Al_2O_3), Nano Boric Acid, Silicon dioxide (SiO_2), Copper oxide (CuO). The base oils used are distilled water, water, vegetable oils like soybean oil, coconut oil, commercial vegetable oils, mineral oil, SAE-40 oil, ester oil.

1. From the above study it is noted that Nanoparticles improve the properties of metal working fluids. Irrespective of base oil, Nanoparticle enriched cutting oils gave better performance than dry cutting in cutting forces and surface finish.
2. Although, water, distilled water, mineral oil, SAE-40 oil performed well and gave better performance it is recommended to use vegetable oil or commercial vegetable oil, because of their biodegradability and higher flash point.
3. Nanoparticles improve the thermal conductivity of the metal working fluids, which results in reducing the overall temperature of machining process.
4. Thermal conductivity of MWCNT is the highest at 6000 W/mK and Copper oxide has the least at 19.6 W/mK.

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