

Effect of Biodegradable metal cutting fluids in machining applications - A Review

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Abstract. The vegetable based metal cutting fluids are widely used in machining applications because of its effectiveness in reducing the cutting temperature, cutting force as well in getting better the tool life and surface integrity. Both the cultivation and production of edible and non-edible oils are comparatively uncomplicated and viable. The sustainability and biodegradability are the two major attributes which expands the usage of edible and non-edible oils in the present scenario while comparing with various technical aspects and feasibilities from the different research work so far reported. This review article is mainly exploring the advantages and usage of vegetable based cutting fluids for various machining applications for yielding better machinability criterion.

Keywords: Biodegradable, metal cutting fluids, edible, non-edible, machinability

1. Introduction

Machining is a mechanical process that involves in the removal of work material into a desired shape with high electrical energy consumption due to presence of relative motion between tool and work material. During the machining process, mild to severe plastic deformation may occur and consequently 99% of the energy is transformed into thermal form and conducted into the workpiece [1]. This review article has elaborating the availability and usage of many edible and non-edible based metal cutting fluids in machining applications. At present in addition to traditional flood cooling methods, several alternative cooling methods like cryogenic cooling, minimum quantity lubrication (MQL) etc., are being used [2]. Rahim et al introduced the supercritical carbon dioxide technique to reduce the heat generation at the tool-chip interface zone [3]. The prime aim of machining process is to



obtain the high quality components at minimal investment. Moreover vegetable based fluids are also being employed in power transformers as insulating and cooling medium [4].

2. General Cutting fluids

Practically metal cutting fluids are unavoidable due to its plenty of advantages in machining process like enhancing the costlier cutting tool life, minimising the occurrence of thermal damage over metal component surface, assisting in clearing the accumulated chips from cutting zone and helping a lot in obtaining the good surface texture.

2.1. Kinds of Cutting fluid

2.1.1. Straight oils: Straight oils are often used in machining where they function effectively in direct form. This oil consists of mineral or petroleum base and may also contain some polar lubricants similar to vegetable oils, fats and esters.

2.1.2. Synthetic Fluids: A synthetic fluid consists of alkaline organic and in-organic compounds alongside additives to prevent corrosion. They function well in diluted form and offer best cooling performance.

2.1.3. Soluble oil: These are formed emulsions by mixing with water. The resulting concentration of emulsion and a base mineral oil to form a stable emulsion. These soluble oils also perform well in their diluted form and provide satisfactory lubrication in addition to heat transfer performance.

2.1.4. Semi synthetic fluids: These are basically combination of soluble and synthetic fluids. In addition their better performance, cost of this kind of fluids is considerably low [5].

2.2. Uses of vegetable based cutting fluid

It is feasible technically to improve the product quality at minimised cutting tool cost, and essentially presenting safe environment through the application of vegetable based cutting fluids. For achieving energy independence and clean surroundings then it is required to use massively available vegetable based cutting oils. Other merits of this kind of oil are:

- diminished frictional coefficient
- High flash point
- Less smoke and fire risk
- Easy clean up
- Safe to operators and environment

3. Edible cutting fluids

The elaborate development of metal working fluids and further utilisation of cutting fluids have resulted in significant industrial revolution. During 18th century, mineral based cutting oils are widely employed in machining applications. However mineral oils are non-renewable whereas edible oils are renewable and offer several advantages for the sustainable manufacturing theme. Edible oils are generally considered and used as food substance other than dairy products which are useful for human consumption. Plant derived edible oil consists of carboxylic acids with long hydro carbon chain. The most commonly used edible oils are coconut oil, corn oil, cotton seed oil, olive oil, palm oil, peanut oil, rapeseed oil, sunflower oil etc. Generally emulsifier has vital role in dissolving the oil in normal water to formulate steady oil in water emulsion. The increased use of petroleum based cutting fluids causing environmental imbalance is a major negative aspect to eco-system. To overcome this adverse effects of using conventional cutting fluids, the production and usage of edible and non-edible based cutting oils have to be motivated which the directed to achieve sustainability machining process [1].

4. Non-edible cutting fluids

Non-edible oils are not suitable for human and animal consumption due to their toxic composition nature. The recent research articles highlight the use of non-edible oils in machining than the edible oils by considering economical and technical features.

4.1. Available Non-edible oils:

- Jatropha crucea
- Calophylluminophyllum
- Mahua
- Pongame oil tree
- Neem oil
- Rubber tree
- Croton megalocarpus

Moreover these non-edible crops have to be planted and cultivated massively at unproductive land areas as well in poverty suffering areas and also in forest as physical boundaries to other useful type of crops.

5. Physical properties of edible and non-edible oils

Normally edible oils are suggested for human intake however non-edible based oil has been completely restricted from consuming due to the presence of toxins. Moreover this is a vital reason why non edible oils are preferred for production of metal cutting fluids. The production of non-edible based oil is comparatively cheaper than the production of edible oils. Since edible oils are human consumable they are not found ideal to use as metal cutting fluids. Various research studies have highlights the eligibility criteria for the use of non-edible oils [6] in industrial applications. Table 1 presents some of the basic physical properties of edible and non-edible oils.

Table 1. Properties of edible and non-edible oil

| Properties | Sunflower oil | Rapeseed oil | Soybean oil | Jatropha oil | Neem oil | Castor oil |
|----------------------------|---------------|--------------|-------------|--------------|----------|------------|
| Kinematic viscosity@40° C | 40.05 | 45.6 | 32.93 | 47.48 | 68.03 | 220.6 |
| Kinematic viscosity@100° C | 8.65 | 10.07 | 8.08 | 8.04 | 10.14 | 19.72 |
| Viscosity index | 206 | 216 | 219 | 208 | 135 | 220 |
| Pour point | -12 | -12 | -9 | 0 | 9 | -27 |
| Flash point | 252 | 240 | 240 | 240 | - | 250 |

6. Experimental Outcomes through the usage of Biodegradable metal cutting fluids

Talib et al. [7] performed some experimental trials to enhance thermal oxidative stability and cooling cum lubrication behaviour of crude jatrophpha. Crude Jatropha Oil (CJO) has been currently acknowledged as an environmentally benign metal working fluid (MWF). The authors have found improvement on the properties of CJO by adding molar ratios of jatropha methyl ester (JME) to trimethylolpropane (TMP) (MJO, MJO3, MJO5) through by addition of various concentrations of Hexagonal Boron Nitrate (HBN) particles ranging between 0.05 to 0.5 wt %. This research article evaluated the machinability aspects such as cutting force, cutting temperature, chip thickness, tool chip contact length, and specific energy with the employment of minimum quantity lubrication (MQL) setup and reported that by adding 0.05 wt% of HBN particles enhanced the overall machining performances. Carbon chain could affect the lubrication performance; CJO containing a high percentage of unsaturated carbon chain could be inferred to use as metal working fluid.

Rao et al. [8] used the minimum quantity lubrication (MQL) technique in their research work. Since the convectional metal working fluids has facing numerous limits in ecological system and disposal of used matters safely hence the concept of MQL is becoming significant. Because of the better properties of vegetable based cutting fluids, enhanced performance during machining process can be yielded compared to mineral oils. Further inclusion of Nano particles in both vegetable based and mineral based oils has been tried by many researches to augment the overall performance. Future research may be directed to improve the individual performance of fluids through viable alternate measures.

Abdalla et al. [9] developed novel sustainable neat oil for machining applications especially with non-edible based one. Further with this oil, they have conducted some experimental trials with the stainless steel and titanium as work materials. The experimental results have revealed that for reducing the cutting force and temperature, vegetable based cutting oil should be preferred.

6.1 Turning Process

Elmunafi et al. [10] used castor oil with a MQL setup having a flow rate of 50 ml/hr along with 5 bar inlet air pressure to turn hardened stainless steel using coated carbide cutting tool. Finally authors have assessed some of the vital machinability aspects: tool life, surface roughness and cutting force were improved considerably. Adekunle et al. [11] made a study on chip morphology and behaviour of cutting tool during turning of AISI 301 with different biodegradable based cutting oils. Elmunafi et al. [12] carried out experimental work with the use of castor oil as cutting fluid. They performed trials under dry condition and also with MQL technique using wiper geometry - coated carbide cutting tool. The outcome shows that the use of MQL seems better to turn the hardened stainless steel using coated tool. The process is limited due to formation of elevated cutting temperature at high cutting speeds and observed that Air - oil mist get evaporated. They also observed that through supply of smaller amount of coolant oil (50 ml/hr) yielded a better tool life.

Dhar et al. [13] observed that the drop in cutting temperature, moderate tool wear and improved surface finish while turning AISI 1060 work material with MQL system filled with vegetable based oil compared with flood and dry machining conditions. Kuram et al. [14] used the canola and sunflower oil based cutting fluids in a MQL system and found good effect on process outcomes like tool wear and surface finish. Ojolo et al. [15] machined the aluminium component with ground nut, coconut oil, palm and kernel vegetable based cutting fluid in a turning process and observed the considerable changes in tool wear. Paul et al. [16] observed that the lower temperature was recorded while using neem oil based cutting fluid compared to conventional soluble oil and other techniques. Yakubu et al. [17] performed machining experiment on aluminium - manganese alloy with neem seed oil based cutting fluid, conventional soluble oil and also at dry condition so as to evaluate surface roughness and tool wear. Experimental results were also compared and presented in the article.

6.2 Drilling Process

Kelly et al. [18] employed MQL setup and used vegetable based oil as coolant medium during drilling of cast aluminium silicon alloy. The machinability characteristics like cutting torque, surface roughness and tool wear were studied under MQL and dry environment. It is observed that vegetable based coolant oil with a MQL technique minimises the torque and enhances the surface finish however found increasing at higher feed rate and cutting speed levels. Costa et al. [19] observed that burr height was smaller at dry machining environment and same was found larger at MQL machining situation.

Rahim et al [20] performed high speed drilling on Ti-6-Al-4V work material with palm oil and synthetic ester based coolant oils in a MQL setup separately and noticed that palm oil reduced the tool wear effectively. Belluco et al. [21] carried out drilling experiments on AISI 316L material with

vegetable based cutting fluid and noticed that the good results are obtained in the process outcomes like tool wear, tool life, cutting force and chip formation. Kuram et al. [22] noticed better improvement on surface finish and declined thrust force with minimised frictional effect while machining with sunflower oil based cutting fluid.

6.3 Milling Process

Kuram et al. [23] noticed that usage of sunflower and canola vegetable based cutting oil helps in obtaining best surface finish, improved tool life and reduced worn out of cutting edges during milling of aluminium work pieces while compared with commercial synthetic oil. Sales et al. [24] studied the effect of different feed rates on tool wear, surface roughness and chip formation aspects during the milling process with MQL setup. It is observed that friction decreases with the increase of feed rate and also there is reduction of tool wear, surface roughness, burr length etc.

6.4 Grinding Process

Kalitha et al. [25] conducted tribological study on soybean oil mixed with MoS₂ nano particles to provide nano lubrication for machining of cast iron using MQL technique and used vitrified bonded aluminium oxide abrasives as grinding wheel material. It is observed that a notable reduction in the coefficient of friction and grinding forces while using soybean oil as a base fluid. This reduction in grinding forces is reduced due to formation of Mo-S-P tribofilm. Guo et al. [26] carried out grinding experiments on Ni alloy to assess the lubrication performance of castor oil while mixed with different vegetable oil. In this study, the castor oil was mixed in 1:1 ratio with vegetables oils. Ultimately they observed that soybean and castor oil mixture showed better performance and reduced the grinding force and specific normal grinding force by 27.03% and 23.15 % respectively while comparing with pure castor oil.

Conclusion

The application of traditional cutting fluids in machining process repeatedly overtime induces chemical changes of fluids due to the environmental effects, contamination from the metal chips and tramp oil. These effects can be easily overcome by the suitable selection and use of edible and non-edible based cutting fluids in order to yield better overall performance and machinability criterion. The various process input parameters like cutting velocity, feed rate, depth of cut, tool geometry and others have to be optimized for getting better overall process outcomes with the applications of these vegetable based cutting fluids. The process of cultivation and production of Edible and non-edible oils are found trouble-free and economical and the process wastage obtained during the extraction of vegetable oil can be easily degradable. Therefore overall machinability aspects of any kind of machining applications can be enhanced by using the edible and non-edible cutting fluids appropriately.

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