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Synthesis of Eco-Friendly Machining Lubricants and Its Tribological Characteristics

D.K. Karupannasamy, R.Ruthuraraj

Abstract*: Use of vegetable oil as a base for the preparation of machining fluids for the replacement for mineral oil is a growing research area because of the harmful effects to the environmental degradation of soil and water affecting plants and aquatic species, health hazards to the workers, bio-degradability and carcinogenic effects. Further most of the research work is carried out by formulating cutting fluids from vegetable oils using petroleum based emulsifiers, which defeats the purpose of using vegetable oils. In the present study lubricants from vegetable oil based emulsions were formulated with food grade emulsifier polysorbate 80. Cutting fluids were formulated by using vegetable oils as a base in an aqueous solution with emulsifying agent in the ratio of 1: 20. The tribological properties of these vegetable oil emulsions were investigated using a rotary type tribometer. The tribometer has a stationary loaded pin made from EN8-steel (workpiece material) which slides over the rotating disc made of EN31-steel. The experiments were performed with two different sliding speeds and four different loads. Coefficient of friction, friction force, wear rate and surface roughness were recorded and analysed. The wear rate of the pins while lubricating with castor oil and mahua oil emulsions was low as compared to palm oil emulsion. At low speed the friction was low with castor oil emulsion, while at higher speed the coefficient of friction was low with mahua oil emulsion. A conclusion has been arrived from the experiments that the castor oil emulsion gave better lubrication properties as compare to palm, mahua and mineral oil emulsions.

***Keywords* : Friction, wear, vegetable oil, machining.**

I. INTRODUCTION

Cutting fluids functions as a coolant and a lubricant in a material removal process to remove the heat generated at the interface and reduce thermal distortion, better tool life, good surface finish and removal of machined chips away from the cutting area. Search for sustainable and environmental friendly cutting fluids as an alternate to mineral oils is never ending research in manufacturing industries and considerable efforts have been put forward to understand the mechanism of cutting fluids. Many countries like United States of America, Japan, Canada, Scandinavia and European Union countries have passed regulations regarding the use of sustainable biodegradable metal working fluids for cleaner production and as a substitute for mineral oil [1]. About 85% of total lubricants (mineral oil base) used all over the world are derived from crude oils with strenuous extraction process [2]. Such excessive use of crude oils greatly affects the agricultural products and food contamination. Among the lubricants metal working fluids are used extensively in metal cutting operations and most of these fluids are derived from mineral oils [3]. It was estimated that European Union alone consumes about immense amount of cutting fluids (320,000 tonnes per year) and nearly about which 75% needs to be disposed [4]. According to Occupational Safety and Health Administration (OSHA), continuous exposure in the production environment causes many health problems including skin disorders, respiratory diseases and cancer. In the aqueous solutions, bacteria and fungi can grow abundant in case of improper maintenance procedure and produce microbial toxins. These toxins pose serious health hazard to workers by infection and affects the immune system [5]. To negate the harmful effects of mineral oils, there are many alternatives explored. Vegetable oil-based cutting fluids are highly biodegradable and hence are environment-friendly, renewable, less toxic [6]. Owing to their innate chemical property and high bio-degradable property, vegetable oil can be a sustainable alternate for lubricants instead of mineral oil. In many cases it has been found that vegetable oil based cutting fluids perform better than mineral oil based cutting fluids during machining process [7]. Vegetable oil-based cutting fluids have better performance because of the better properties in comparison to the mineral oil for flash point, viscosity, lubricity and evaporative loss to the environment when subjected to heat [8]. However the limiting factors of vegetable oils to be used as an industrial lubricant are ease of oxidation, poor stability in aqueous environment, thermal stability, limited cold flow properties due to fatty acids and tribological behavior. These disadvantages in vegetable oils could be overcome to improve lubricity by the using additives for emulsification, extreme pressure and temperature sensitivity, corrosion resistance, physical and chemical bondability, foam resistance, acidic and alkaline regulator.

Since the beginning of industrialization, mineral oil based lubricants have been used for many applications such as gear boxes, internal combustion engines and metal working application. However, it has been found that vegetable oil with same viscosity perform better as lubricant compared to mineral oil. This can be ascribed to a property of vegetable oil called “oiliness” or “lubricity” [9]. Lubricity is defined as the property of vegetable oil to coherently adhere to metal surface and the orientation of hydrocarbon chains to the adhering surface.

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* Correspondence Author

D.K. Karupannasamy*, Department of Mechanical Engineering, Kongu Engineering College, Perundurai, India, Email: k.dineshkumar@yahoo.co.in

R.Ruthuraraj, Department of Mechanical Engineering, Kongu Engineering College, Perundurai, India, Email: ruthuraraj@gmail.com

If the chains are perpendicular to the surface, adherence will be better. Due to the above mentioned advantages, vegetable oils can be a viable substitute to petroleum oil based lubricants. Kumar Ujjwal et al., [10] investigated the role of vegetable oils (castor oil and coconut oil) in turning of Aluminium (AA1050). From the experiments, it is evident that vegetable oil-based lubricants have good surface finish as compared with traditional oils used in industries. Xavior et al., [11] conducted turning experiments using a carbide tipped tool for AISI304 steel to study the lubrication properties by examining tool wear and surface topography. Experimental results have shown that the coconut oil performs well in comparison to mineral oil for wear reduction of cutting tools and obtaining superior surface finish in work-piece. Shah Mithun [12] used non-ionic surfactants Tween 20 to formulate emulsion of castor oil with water to formulate vegetable oil-based emulsion for machining of AISI-316-L Steel. It was concluded that in the turning operations, using castor oil emulsion reduced cutting force by 24%, and tool wear by 27% against mineral oil emulsion. Lawal et al., [7] devised design of experiment with a full factorial method in for formulating cutting fluids using palm kernel, cottonseed oil and mineral oil. The experiments shows that both palm kernel oil and cotton seed oil have good machining characteristics of AISI-4340 steel with coated-carbide tools. Katna Rahul et al., [13] formulated neem oil based emulsifier with polysorbate as emulsifier and used it for turning of EN 8 steel. The neem oil performed better than the mineral oil in all the areas like cutting forces, wear and surface finish. It can be concluded from the literature, that there is a growing interest in vegetable oils and there is a lack of research in characterization of the tribological properties of Vegetable oil emulsions. Hence in the present study, tribological properties of the emulsions using castor oil, mahua oil and palm oil are evaluated using Pin on Disc Tribometer.

II. EXPERIMENTAL METHODOLOGY

A. Preparation of Lubricant

From the literature survey, three vegetable oils are selected namely Palm oil, Castor oil and Mahua oil. The viscosity of the oils used in the experiment can be found in Table I. The emulsion is prepared using polysorbate 80 as emulsifier. The advantage of this emulsifier is that it can be used for hard water also. The oil emulsion mixture is blended with water in the ratio 1:20.

B. Preparation of Pin

Pin material used is EN8 steel, the dimensions of pin are length 25mm, and diameter 8mm. The pins are first subjected to rough facing in a lathe and then they are polished using various grades of emery sheets from course to fine grade to obtain smooth surface to negate the artifacts of surface roughness on the measurement of friction and wear. The chemical and mechanical properties of EN8 steel are shown in Table II and Table III.

C. Friction and Wear evaluation

The evolution of friction and wear for machining conditions is evaluated according to the ASTM G99 with a standard tribometer as shown in Fig. 1. The specifications of the rotary type tribometer is shown in Table IV. The pin is machined from EN8 steel of ø8x25mm and the disc is machined and ground from EN31 steel of ø180mm with a measured hardness of 60HRC and usable diameter of ø140mm for friction and wear testing. The disc and pin are placed parallel to each other in order to ensure the maximum contact. The perfect sliding condition is ensured between the loaded pin and horizontally rotating disc which is lubricated with Vegetable oil-based emulsion. Constant flow of lubricant is supplied over the rotating disc at a flow rate of 66 ml/minute. The experiments are carried out at a room temperature. The present study is carried out under four different loads 40N, 80N, 120N and 160N and two speeds 300rpm and 900rpm respectively. The weight of the pin is measured before and after the experiments to calculate the weight loss. The experiments are conducted for a constant sliding distance of 3600m.

Fig. 1.Pin on Disc Tribometer Setup

The friction coefficient is calculated as the ratio of measured friction force to the applied normal load using the Equation,

$$\mu = F/N \quad (1)$$

The friction force is measured by means of force transducer and the normal load is the dead weight attached to the arm of the tribometer which is then transferred to the contact area of the pin.

The volume loss of the pin is calculated by recording the weight of the pin before and after the experiments. The weight of each pin is measured thrice using the digital balance and the average value is considered in order to reduce any possible error in the measurements.

The wear rate is calculated using the below Equation,

$$Q=\Delta V/s \quad (2)$$

Where,

Q - wear rate in mm^3/m,
ΔV - volume loss, mm^3
s - sliding distance, m.

Table- I: Chemical composition of EN8 Steel

Vegetable Oil	*Kinematic Viscosity (cSt at 32°C)*	*Kinematic Viscosity (cSt at 100°C)*
Palm oil	86.33	13.97
Mahua oil	97.38	18.77
Castor oil	594.6	28.47

Table- II: Chemical composition of EN8 Steel

Material	***Percentage***
Carbon	0.44
Silicon	0.40
Manganese	1.0
Sulphur	0.05
Phosphorous	0.005

Table- III: Mechanical properties of EN 8 steel

Property	***Value***
Maximum stress	850 N/mm^2
Yield stress	465 N/mm^2
Proof stress	450 N/mm^2
Elongation	16%
Hardness value	255 BHN

Table- IV: Pin on Disc Machine Specifications

Test Parameters	***Specification***
Standard	ASTM G99
Sliding speed range	0.26 to 10 m/s
Disc Rotation Speed	100 to 2000 rpm
Specimen pin diameter	3mm to 12mm
Pin length	25mm to 30mm
Wear Track Diameter	10mm to 140mm
Lubricant tank capacity	3 Litres
Flow rate	10 ml/min to 1litre/min

III. RESULTS AND DISCUSSIONS

A. Effect on Coefficient of Friction

Friction coefficient is termed as the measure of resistance offered by the material for the object sliding over the object. Fig. 2 depicts the effect of friction at four different loads and a constant sliding speed of 300 rpm. It is evident that the friction shows an increasing trend for the applied load in mahua oil and palm oil but decreases at load of 160 N. The castor and mineral oil shows a decreasing friction coefficient over the load.

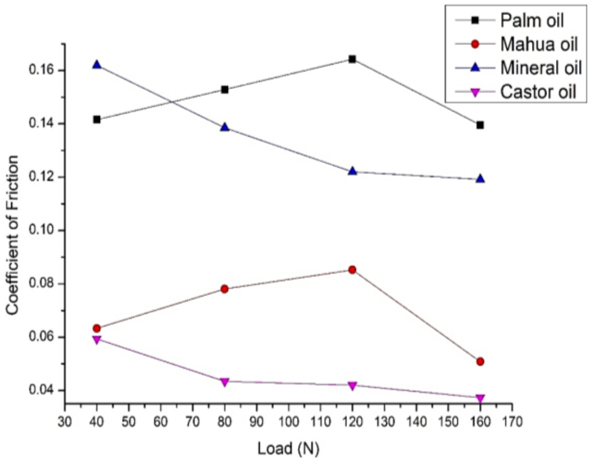

Fig. 2.Effect on Coefficient of Friction with Different Loads at 300 rpm.

The coefficient of friction for castor oil and mahua oil are quite similar at the loads of 40N and 160N, but at 80N and 120N the coefficient of friction values are low for castor oil emulsion. Therefore, it can be concluded that at 300 rpm the friction is the lowest for castor oil emulsion as compared to other three emulsions. The lower friction can be related to the higher viscosity of castor oil and its better lubricity.

The measured friction value at different loads for a constant speed of 900 rpm is illustrated in Fig. 3. In the broad view, the friction values are reduced for all oils as compared to lower speed (300 rpm) which is due to hydrodynamic lubrication. It is also seen that at higher speeds, the friction for mahua oil is comparatively low when compared to other oil emulsions. The friction value is comparatively lower for mahua oil which is because of the formation of fatty layer surrounding the pin which acted as a lubricating layer between the pin and the disc.

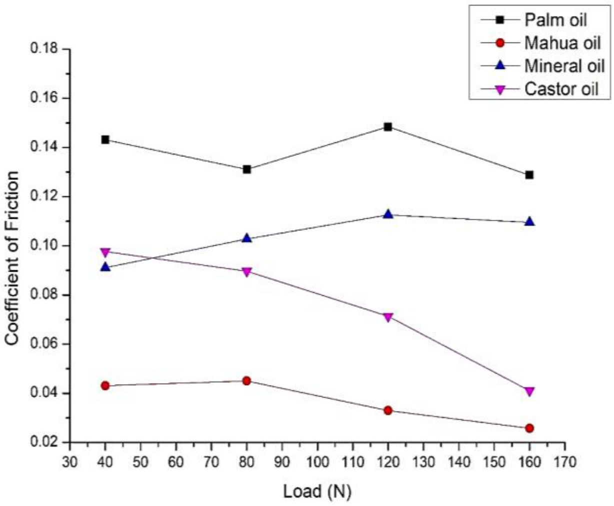

Fig. 3.Effect on Coefficient of Friction with Different Loads at 900 rpm.

B. Effect on Wear rate

The rate of wear of the pin material is calculated by the weight loss method, which is the weight of the pin is measured before and after the experimentation to find out the weight lost during sliding. Fig. 4 shows the wear rate comparison for the three vegetable oil emulsions. The higher wear rates are observed while lubricating with palm oil emulsion, and at 160N the highest wear rate is obtained for palm oil emulsion. At 300 rpm the wear rates are low for both castor oil and mahua oil emulsions. While conducting experiments with castor oil emulsion as cutting fluid at higher loads an oxide layer is formed similar to rust surrounding the eroded zone, which acts as a lubricating layer and reduced the wear rate. Similar observations were made by Acilar Mehmet et al., [14] in their work, and this wear mechanism is oxidative wear.

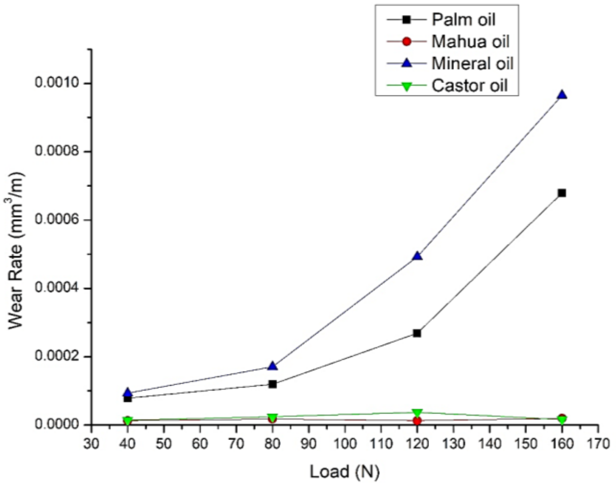

Fig. 4.Effect on Wear Rate with Various Loads at 300 rpm.

Fig. 5 shows the effect on wear rate while lubricating with the three vegetable oil emulsions at four different loads and constant speed of 900 rpm. The highest wear rate is observed for palm oil emulsion whereas the lowest wear rate is obtained for mahua oil emulsion. The low wear rate for mahua oil emulsion at 900 rpm is due to formation of fatty layer around the pin which acted as lubricating layer and reduced the wear.

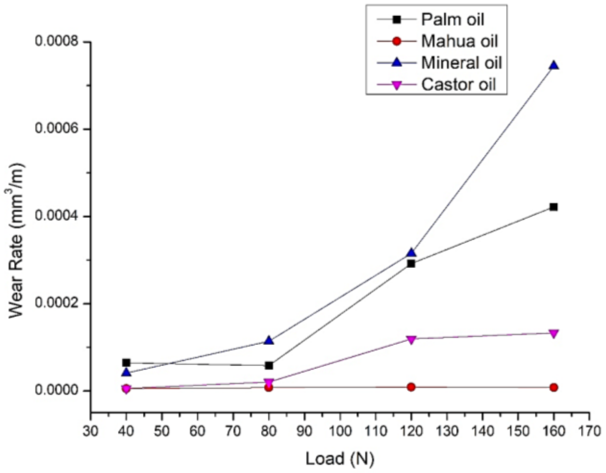

Fig. 5.Effect on Wear Rate with Various Loads at 900 rpm.

C. Effect on Surface roughness

Surface roughness can be related to coefficient of friction and frictional force since an increase in surface roughness indicates higher friction force. In the present study surface roughness of pin is measured before and after test for two loads 40 N and 160 N for the highest sliding speed 900rpm using surface roughness profilometer. Fig. 6 shows the comparison of pin material for the surface finish of castor, mahua and palm oil emulsions against the mineral oil. For the load of 40N castor oil gives low surface roughness as compare to other emulsions, also for the load of 160N surface roughness was very much reduced while using castor oil emulsion. The lower surface roughness while lubricating with castor oil emulsion is due to high viscosity of castor oil. The same order of roughness is also observed in mahua oil. Mahua oil and castor oil has superior performance when compared to mineral oil.

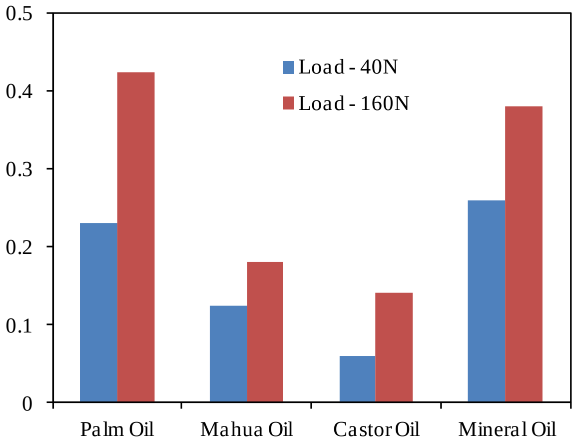

Fig. 6. Effect on Surface Roughness for Different Loads at 900 rpm.

D. Results and Discussion

In the present work three vegetable oil emulsions were prepared form palm oil, castor oil and mahua oil with polysorbate 80 as emulsifier. The tribological properties of these emulsions were analysed for the coefficient of friction, friction force, wear rate and surface roughness and the following conclusions are summarized:

- Coefficient of friction and friction forces at 300 rpm are low for castor oil emulsion as compared to other emulsions but at 900 rpm. The coefficient of friction and friction forces are low for mahua oil emulsion.
- Wear rate is considerably reduced while using castor oil and mahua oil emulsions as lubricants.
- The pins lubricated with castor oil emulsion have superior surface finish in comparison with other three emulsions.
- Though the tribological properties are quite similar for both castor oil and mahua oil emulsions, the formation of fatty layer while lubricating with mahua oil is a hindrance during experimentation as it tends to stick all over the machine.
- It is concluded that castor oil emulsion exhibits better tribological properties when compared to other emulsions.
- Polysorbate 80 which is a food grade emulsifier can be used as a substitute for eco-friendly reasons without any reduction in performance.

E. Other Recommendations

- The growth of micro-organisms in cutting fluid is a major concern, hence the cutting fluid has to be optimized by adding additives to cutting fluid.
- The vegetable oil emulsion can be used as cutting fluid for turning in CNC machine and its performance can be analysed for cutting force measurement and surface quality of the products.
- Nano particles can be added to vegetable oil emulsion to improve its properties.

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AUTHORS PROFILE

DineshKumar Karupannasamy is as an Associate professor in Kongu Engineering College, Perundurai. He has done PhD in Tribology to research on the evolution of friction conditions prevailing during a deep drawing process. His research area includes tribological study of friction and wear in deep drawing, rolling, forging processes, etc., contact mechanics and Finite element methods.

R. Ruthuraraj is as an Assistant professor in SNS College of Engineering, Chennai. He has done research work in Tribological analysis of lubricants as a research scholar. His research area includes Tribology, analysis of friction and wear in materials, manufacturing, machining and design of experiments.