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Research Article

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Tribological property evaluation, optimization and performance of waste sunflower oil based green cutting fluid with silicon dioxide nanoparticles as additive

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ABSTRACT

Mineral oil-based cutting fluids are hazardous and non-biodegradable, and their widespread usage has had a terrible effect on the environment and living things. The creation of a novel, ecologically sustainable cutting fluid technology is essential to avoid the above crisis. Commercial mineral oil alternatives are considered to possess identical lubricating properties as vegetable oils. Most vegetable oils are edible, so waste-cooking sunflower oil (WSO) is selected from this group to serve as the base stock for the green cutting fluid. The green cutting fluid is created using silicon dioxide nanoparticles as an additive and food-grade emulsifiers like Tween 80 and Span 80. According to the experimental findings, 0.05 weight percent silicon dioxide nanoparticles in the green cutting fluid performed better on a pin-on-disc tribometer.

KEYWORDS: Waste sunflower oil, Green cutting fluid, Silicon dioxide nanoparticle, Food grade emulsifiers

INTRODUCTION

All industrial sectors use lubricants to keep their equipment and components lubricated. Mineral-based oils account for over 85% of all lubricants used globally (Pop *et al.*, 2008). Still, a large proportion of cutting fluids used in industries are made from mineral oil. Regular interaction with mineral oil-based cutting fluid has deleterious effects on human health and the environment. The predominant adverse effect is associated with their improper usage, which causes air pollution, soil contamination, groundwater contamination, and surface water contamination, and therefore contaminates agricultural commodities and food (Bírová *et al.*, 2002). The effects of mineral oil mists on human health, specifically on the respiratory system, are harmful when they are mixed with nitrogen dioxide. Degraded mineral oils are a source of heterocyclic and poly-aromatic rings, which are known to cause skin cancer and other health issues in living things (Abdalla *et al.*, 2007). According to reports, skin contact with cutting fluids is the cause of nearly 80% of all occupational diseases among operators (Bennett, 1983).

One of the lubricant types that is often used in machining processes is metalworking fluid. Metalworking fluids (MWFs) are available in wide varieties and may be used for a variety of purposes. Using cutting fluid for machining applications, promotes surface finish and precision, extends tool life, and improves the quality of the workpiece (Abdalla & Patel, 2006). Vegetable oils, which have strong lubricating qualities and thermal stability, can be used to create biolubricants, whether they are edible or not. Vegetable oils have a biodegradability of about 70-100%. Cutting fluids made from vegetable oil are regarded as being safe (Debnath *et al.*, 2014) for both the environment and human health. Low toxicity, a high flash point, and high viscosity are all characteristics of vegetable oils (Mobarak *et al.*, 2014).

The use of green cutting fluids has gained great attention in the era of green machining and green manufacturing. Several studies about green cutting fluids are reported in various vegetable oils like rapeseed oil (Belluco & De Chiffre, 2004) and shear butter, palm kernel oil (Mahadi *et al.*, 2017; Abdollah *et al.*, 2020), coconut oil (Xavior & Adithan, 2009), rice bran oil (Edla *et al.*, 2022), sunflower oil (Ozcelik *et al.*, 2011), avocado oil (Reeves & Menezes, 2017), pongamia oil, cottonseed oil, canola oil, sesame oil, jatropha oil (Talib & Rahim, 2018), and groundnut oil (Rashmi *et al.*, 2019). The lubricating qualities of the base oil, particularly its tribological properties, determine its stability and usability. In this present study, we focus on developing a green cutting fluid using WSO as the base oil. WSO has poor tribological characteristics; thus, the application of non-toxic nanoparticles can be thought of as a possible technique to improve these features. According to several researches, SiO_2 nanoparticles are a reliable, harmless addition to enhance tribological qualities (Peng *et al.*, 2010; He *et al.*, 2017). The main difficulty when utilising nanoparticles as an addition is maintaining a stable suspension free from agglomeration and sedimentation for a prolonged period of time. Vegetable oils containing SiO_2 nanoparticles have shown excellent dispersion stability without coagulation or precipitation after a considerable period of time, according to previous research (Anoop *et al.*, 2014).

In these water-soluble cutting fluids, emulsifiers are regarded as one of the essential factors. Tween 80 and span 80, two typical emulsifiers used in the food and cosmetic sectors, are included in this study to formulate the green cutting fluid in the ratio of 1.5:1.5. It was shown that using these emulsifiers together enhanced their antibacterial effects and made them more effective when used alone in an acidic medium (Hg *et al.*, 2011). Very few works with waste sunflower oil as a base oil and silicon dioxide nanoparticles as additives for green cutting fluids were reported in the field of bio-lubrication. In the present study, the major constituent of the green cutting fluid was derived from used vegetable oils, and silicon dioxide nanoparticles with different proportions such as 0.01 weight percent, 0.05 weight percent, and 0.1 weight percent were added. After selecting the best combination among them based on tribological properties and with emulsifiers, the cutting fluid was formulated, and a performance test was carried out in a standard pin-on-disc tribometer.

EXPERIMENTAL INVESTIGATIONS

Materials

WSO was collected from different hotels in Thiruvananthapuram, Kerala, India, and silicon dioxide nanoparticles were purchased from Avra Chemicals in Bengaluru, Karnataka, India. Emulsifiers such as Span 80 and Tween 80 were purchased from TCI Chemicals Pvt. Ltd. and Spectrochem Pvt. Ltd. respectively.

Tribological Property Evaluation

All of the samples' tribological characteristics, including wear scar diameter (WSD) and coefficient of friction (COF), were assessed using a common four-ball tribo tester in accordance with ASTM D 4172 which is shown in Figure 1. Chrome alloy steel balls with a diameter of 12.5 mm were the balls utilised in the test. Acetone was first used to clean the balls and ball pots. After that, an oil sample was transferred to the ball pot along with three test balls. The fourth ball, which was fixed to the collet, was inserted into the mandrel of the four-ball tribo tester, which was attached to the motor spindle. 75 °C cabin temperature, 1200 rpm spindle speed, and a 392 N load applied for 1 hour were the test conditions that were maintained.

Green Cutting Fluid Formation

The green cutting fluid was formulated using three combinations of WSO and 0.01 weight percent, 0.05 weight percent, and 0.1 weight percent silicon dioxide nanoparticles blended by using an ultrasonicator, and three combinations of base oil are produced, which are shown in Figure 2. Among them, a better combination of silicon dioxide nanoparticles and waste sunflower oil is selected, and Tween80 and span80 emulsifiers are mixed in different combinations, which are shown in the Table 1 and Figure 3. The base oil and the emulsifier combinations are kept in a hot air oven at 110 degrees Celsius for a period of time. The green cutting fluid (GCF) was created using WSO in a water emulsion with a ratio of 1:20.

Corrosion Stability of the Green Cutting Fluid

The corrosive stability of the prepared emulsion was tested using cast iron chips and the filter papers using the ASTM D 4627 standard, which is shown in Figure 4.

Performance Evaluation

According to the ASTM G99 standard, the performance test was carried out at room temperature using a pin-on-disc tribometer (DUCOM TR-20LE-THM400-CHM400). The test disc is composed of EN31 material and has a 64 HRC hardness which is shown in Figure 5. A pin of size 10 mm is used for the test under different load and speed conditions.

Surface Roughness Measurement

The surface roughness of the pin material is calculated using Mitutoyo surface roughness measuring equipment according to ASTM D4417 standards shown in Figure 6.

Figure 1: Fourball tester and optical microscope

Table 1: Emulsion combinations

TWEEN 80 (mL)	SPAN 80 (mL)	Oil (mL)	Water (mL)	Name
2.5	2.5	5	200	WSO-50
2	2	6	200	WSO-40
1.5	1.5	7	200	WSO-30

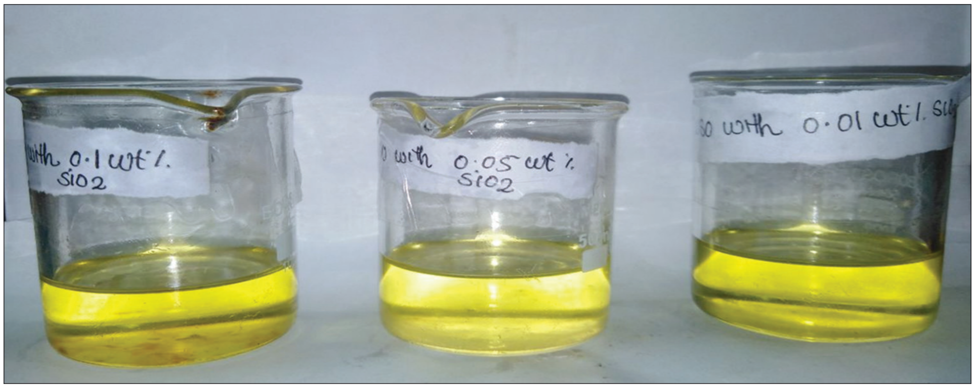

Figure 2: Different combination of WSO with silicon di oxide nano particles

Figure 3: Emulsion combinations

Figure 4: Corrossion stability test

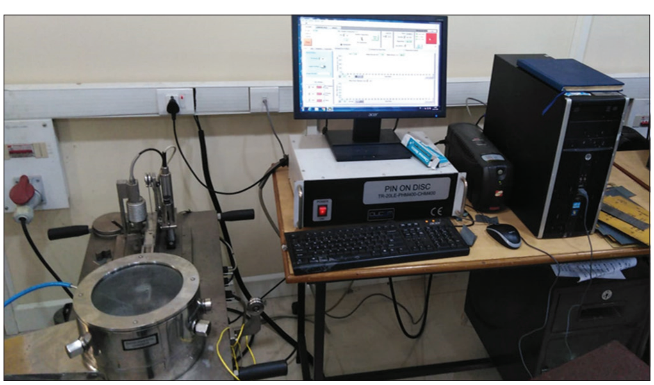

Figure 5: Pin on disc tribometer

Figure 6: Mitutoyo surface roughness measuring equipment

RESULTS AND DISCUSSION

Tribological Analysis

The three combinations of WSO and silicon dioxide nanoparticles are evaluated using a standard four-ball tribo tester, and the following coefficient of friction (COF) and wear scar diameter (WSD) are obtained, as shown in Table 2.

According to the findings, adding 0.05% SiO_2 to WSO decreased the COF value equally and significantly because of the rolling action of nanoparticles. Moreover, they progressively accumulate on the surface, generating a thin coating that prevents direct contact (Sayuti *et al.*, 2014; Xie *et al.*, 2016; Thampi *et al.*, 2021). The ideal concentration of SiO_2 nanoparticles in WSO is specified at 0.05 weight percent. By using the WSO and 0.05 wt% silicon dioxide nanoparticles as the base stock for the green cutting fluid and using the 1.5:1.5 (WSO-30) ratio emulsifier combination, a water-based green cutting fluid is formulated, as shown in Figure 7.

Corrosion Analysis

The corrosion stability test results show that the newly developed green cutting fluid forms a lesser amount of corrosion on the cast iron chips. It can be confirmed by analysing the filter papers used for the test, which are shown in Figure 8.

Performance Evaluation of Green cutting fluid

The performance evaluation of green cutting fluids was carried out on the pin-on-disc tribometer by varying the speed of the rotating disc and keeping the load at 40 N and wear track diameters 60 centimeters which were kept constant. The COF of the green cutting fluid is calculated by the device using the software Winducom and the weight loss of the pin material and the surface roughness is calculated, which is shown in Table 3. The results obtained from the pin-on-disc tribometer, the developed green cutting fluid showed better performance and have a low coefficient of friction and better surface finish. During the performance evaluation, the COF of the green cutting fluid was low at a low speed, and while the COF was increasing with the speed of rotation of the disc, it reached a limit and then decreased due to the low metal-to-metal contact.

Figure 7: Formulated green cutting fluid

Figure 8: Corrosion stability analysis

Table 2: COF and WSD of WSO at various nano-SiO_2 concentrations

Sample	COF	WSD (µm)
WSO	0.0596	691±0.020
WSO+0.01wt %silicon dioxide nanoparticles	0.041	655±0.015
WSO+0.05wt %silicon dioxide nanoparticles	0.032	543±0.005
WSO+0.1wt %silicon dioxide nanoparticles	0.104	652±0.015

Table 3: Performance test results

S. No.	Speed (rpm)	Load (N)	COF	Weight loss (gm)	Surface roughness (µm)
1	200	40	0.0141±0.0015	0.000272±0.00020	0.254±0.002
2	400	40	0.0152±0.0002	0.00298±0.00003	0.267±0.001
3	600	40	0.0168±0.0005	0.00321±0.00025	0.327±0.005
4	800	40	0.0157±0.0001	0.00375±0.00085	0.321±0.001

CONCLUSION

In this study, SiO_2 nanoparticles are added to WSO to create a bio-cutting fluid. The performance, optimisation, and tribological analysis of the developed green cutting fluid are assessed. From the current investigation, the following results are derived: 1) The optimal weight percentage of nano-SiO_2 in WSO is determined to be 0.05 wt% based on the tribological findings. 2) The silicon dioxide nanoparticles can with stand the green cutting fluid without agglomeration and sedimentation after a long period of time. 3) The developed green cutting fluid shows better performance on a pin-on-disc tribometer with a low coefficient of friction and provides a better surface finish.

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