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Development of Bio-Based Cutting Fluid from Roselle Oil with Titanium Dioxide Nano Additive for CNC Machine Turning Operation

Mohammed Sani Haruna[a], Muhammad Usman Kaisan,[b]* Muhammad Ibrahim Kawule[c] Abdulkabir Aliyu[d]

[a]National Agency for Science and Engineering Infrastructure, Idu Industrial Layout, Abuja, Nigeria
[b]National Agency for Science and Engineering Infrastructure, Idu Industrial Layout, Abuja, Nigeria
[c]Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria

[d]Energy Commission of Nigeria, Abuja, Nigeria

* Corresponding author. Tel.: 234-803-694-3404; *E-mail address:* muhammad.kaisan@naseni.gov.ng

Abstract

The research work titled Development of Bio-Based Cutting Fluid from Roselle Oil with Titanium Dioxide Nano Additive for CNC Machine Turning Operation was carried out in in line with the global best practices of ensuring sustainable production during Computer Aided Manufacturing. Nano additive were collected in three different samples base oil 0 wt %, 0.5wt% and 1wt% of TiO_2. Viscosity test was carried out using a viscometer with base oil, 0.5wt% and 1.0wt% having 3.19, 2.86 and 2.75m²/s respectively. Furthermore, the identification of unknown materials and confirmation of the sample materials were analyzed using FTIR spectroscopy with the materials being identified as carboxyl, hydroxyl, alkane, amide carboxyl and amide acid. Turning operation was carried out on a Harrison center machine with a mild steel work piece at constant depth of cut (1.5mm), constant feed rate (0.3mm) and cutting speeds at 80, 160 and 240rev/min. tool wear, surface finish, chip thickness and chip formation were analyzed. With an increase in Nano fluid concentration of 0.5wt% and 0.1wt% relative to base oil, a decrease in kinematic viscosity has been observed. In comparison to base oil and 0.5wt% TiO_2, Nano fluid equal to 1.0wt% TiO_2 shows enhanced results. When titanium dioxide was added instead of base oil, tool wear and surface finish are enhanced more. The percentage increase in nanoparticles, along with the observed changes in chip thickness, shape, and formation, point to the importance of nanoparticles at the tool/workpiece interface.

Keywords: Roselle; Titanium Oxide; CNC; CAM; Nano Additive

1. Introduction

In the twenty-first century, with environmental protection consciousness enshrined in law and regulation, cutting fluid that is environmentally friendly has become common. Vegetable oils, bio cutting fluid, and certain chemically synthesized fluids as esters, such as phosphate esters, poly-alkene glycols, poly-alpha olefins (PAOs), alkylated aromatics, and poly butanes, dominate the market for environmentally friendly cutting fluid (Gajrani et al, 2016). Vegetable oils have historically been used in the food industry, but recent developments indicate that they may also be used as industrial fluids (Agrawal et al, 2014). Traditional cutting fluids began to cause problems for factories over time as the chemicals in them caused serious health effects on employees and the environment. Along with the economic and technological aspects of the production processes, there are other factors to consider. Environmental protection of goods has also become a major source of concern, owing to the fact that environmental authorities and the government have enacted stringent regulations to protect workers' health and the environment. As a result, it's important to look at what steps can be taken to reduce the negative effects of metalworking fluids as much as possible. Mineral-based oils are limited in supply because they are a scarce resource that is rapidly depleting, whereas vegetable-based cutting fluids are long-lasting. There are few reports on machining with vegetable-based cutting fluids in the literature. Because of their higher biodegradability and ability to reduce waste treatment costs, vegetable oils are becoming more common as metal working fluids. It also reduces the health risks to operators which were quite common with petroleum based mineral oils due to their lower toxicity. Cleaner and healthier work environment having less mist in the air is main point. For above mentioned reasons, vegetable oils as metalworking fluids are eco-friendly and are also better lubricant as compared to others. Above all they are extracted from renewable sources and thus unlimited and sustainable. Cutting at high speed and feed generates high temperature. Use of cutting fluid at high temperature has possibilities of smoke formation and fire hazard. Vegetable oils have a higher flash point compares to mineral oils which reduce smoke formation and fire hazard. Vegetable oils have high viscosity index. Viscosity of oil also effect machining productivity. The viscosity of the oil has an effect on machining efficiency as well. Since vegetable oils have a higher viscosity index, their viscosity decreases more slowly than mineral oils as the temperature rises (Gajrani et al, 2016).

High temperatures produced during machining have a significant impact on work piece quality and dimensional accuracy. Friction between the tool work piece and the tool-chip interface causes these high temperatures. Good lubrication in the machining zone can help to manage this. Cutting fluids serve as both lubricants and coolants, reducing friction while also removing heat (Gajrani et al, 2016).

Friction generates a great deal of heat during machining, which is detrimental to the tool and the job. Cutting fluids help to reduce the negative effects of temperature and achieve the optimal surface quality while also increasing tool life and thereby increasing output volume (Katna et al, 2017).

The aim of this research is to test the performance of titanium oxide Nano additive using roselle oil with CNC lathe machine; develop cutting fluid (coolant) from roselle oil and analyse the fluid using FTIR and viscosity test; carryout turning operation on CNC lathe machine; evaluate cutting parameters like tool wear, surface finish, chip thickness and chip formation.

Poor biodegradability of petroleum-based oils and various health hazards associated with synthetic oils have necessitated the development of eco-friendly and biodegradable lubricants from renewable sources. The bio-based lubricants in conventional machining operations can serve as a potential alternative. The vegetable oils generally possess a high flash point, fire point and better thermo physical properties which can be further enhanced by using proper additives.

Scope of this research is limited to development of cutting fluid using roselle oil and analyse viscosity and FTIR and also to carry out the turning operation of lathe machine, evaluate cutting parameters like tool wear, chip thickness, chip formation, and surface finish.

Nomenclature

α	Rake Angle
β	Clearance Angle
γ	Wedge Angle
TiO_2	Titanium Oxide
$d1$	$Dia.\ of\ the\ work\ surf.\ before\ machining$
$d2$	$Dia.\ of\ the\ work\ surf.\ after\ machining$
$Kinematic\ viscosity$	
η	$Absolute\ Viscosity$
ϱ	Density
t	Time of flow of the sample
to	Time of flow of the reference

1.1. Structure

Sachin et al., (2014), worked about Experimental Investigations into Wear Characteristics of M2 Steel Using Cotton Seed Oil in their research they investigate the effect of wear on M2 steel cotton seed oil among various vegetable oil has been taken. Effect of different lubricating conditions on wear and frictional force at various sliding speed and load has been studied. Comparative analysis of different lubricants in terms of weight loss and coefficient of friction has been done. Naeem, et al., (2017), worked on the ''Optimize the Roselle (Hibiscus Sabdariffa L.) Seeds Oil Extraction using Screw Press''. This work was aimed to obtain the optimum rotational speed, temperature of screw press to improve the properties of extracted roselle seeds oil, time of extraction and motor power. In the fact, seeds of roselle plant are full of nutritional constituents, however in Egypt, which they are considered as a by-product. Twenty-one samples were extracted in laboratories of Fats and Oils Department and Mechanical Engineering Department, National Research Centre, Cairo, Egypt; and analyzed during annual season of 2017. The oil yield and quality were investigated.

Nkafamiya, et al., (2017), worked on Effect of storage conditions on the degradation of roselle (Hibiscus sabdariffa) seeds oil. Degradation of edible oil toward rancidity is wasteful and/or health challenging. In this study, oil extracted from Roselle seeds was analyzed for elemental and microbial content. The oil under different conditions of storage (lightened L, dark air-free AF and dark air-tight/covered ATD conditions) were progressively studied for 16 weeks to investigate the changes in the physicochemical properties signaling deterioration. Fourier transformed infrared (FTIR) analysis before and after the storage period were carried out to investigate the changes in the functionality of the oils.

Rahul et al., (2017), worked on Green Manufacturing – Performance of a Biodegradable Cutting Fluid. In their research Huge quantity of petroleum and mineral based cutting fluids mixed with carcinogenic additives to increase their performance are used every year in the manufacturing industry.

Rahul et al., (2019) worked on Nonedible vegetable oil-based cutting fluids for machining processes – a review. The purpose of this review article was to apprise the readers with the current trend in the application of nonedible vegetable oils and their application in machining. This research entails various aspects of cutting fluids and an up to date and exhaustive review on the latest literature on the effectiveness of nonedible oils and its modified versions, blended oils, ionic liquids, and Nanoparticles as additives is done to understand the efficacy of nonedible vegetable oil-based cutting fluids.

Research is ongoing in the areas of biodiesel, bio-based transformer oil and bio based lubricants as it relates to Nano additives for computer aided manufacturing in CNC operations. (Duc et al., 2021) investigated the Novel Uses of Al2O3/Mos2 Hybrid Nanofluid in MQCL Hard Milling of Hardox 500 Steel In order to apply the minimal quantity cooling lubrication (MQCL) technology to the hard milling of Hardox 500 steel, very little cutting oil is used in the process. Furthermore, the foundation fluid of the Al2O3/MoS2 hybrid nanofluid is rice bran oil, a naturally biodegradable oil. The effects of nanoparticle concentration, cutting speed, and feed rate on surface roughness were investigated using an ANOVA analysis. The results show that good surface quality is attained, and the cutting speed is greatly enhanced to 140 m/min (approximately 2.55-2.80 times greater than the advised) values) as a result of the improved cooling and lubricating effects of the MQCL system and the hybrid Al2O3/MoS2 nanofluid. In addition, the surface's microstructure demonstrates how MoS2 formed. using Al2O3/MoS2 to create tribo-films.

Accordingly, (Kazeem et al., 2022) gave a summary of the many vegetable oils utilized in the machining of engineered materials. On the cutting force, the surface smoothness of machined components, the tool wear, and the temperature of the cutting region, the impacts of virgin vegetable oils, emulsified vegetable-based oils, and vegetable-oil-based Nano-cutting fluids were carefully examined. Studies have shown that vegetable-oil-based cutting fluids meet cleaner manufacturing standards when compared to cutting fluids based on mineral oil with enough or superior efficiency.

Furthermore, (Divya et al., 2020) focused on using vegetable oil (coconut oil) mixed with Nano powder as a coolant for textured cutting tool inserts during turning. The outcomes of textured inserts with Nano powder mixed cutting fluid (NPMCF) are contrasted with those of textured inserts with solid lubricant incorporated. As a result, it can be said that tool inserts with a textured surface operate better while using NPMCF as coolant. NPMCF-textured inserts have an efficient lubricating and cooling function as well as facilitating infiltration, spreadability, and absorption. The investigation's findings showed that textured inserts with NPMCF are crucial to achieving improved machining performance and sustainability.

Interestingly, (Mohan et al., 2007) worked on a comparative research of dry machining, wet machining using coconut oil-based fluids, and mineral oil-based fluid was undertaken. Cutting fluids are in charge of lowering the temperature at the tool-to-workpiece interface, lowering the cutting force, facilitating chip removal, boosting the material removal rate (MRR), improving lubrication between tool and workpiece, and ultimately improving surface smoothness. The ideal flow and heat transfer criteria for cutting fluids are strong heat conductivity, low viscosity, higher heat removal rate, good lubricating capacity, and specific heat. Mineral oil has traditionally been used as the foundation fluid in the production of lubricants like cutting fluids. These fluids' various characteristics are also discovered. By employing EN-19 steel as the workpiece material on a CNC Turning Centre.

Aggarwal et al., (2008) confirmed that, in CNC turning of AISI P-20 tool steel utilizing liquid nitrogen as a coolant, various variables (tool life, cutting force, surface roughness, and power consumption) were adjusted. Cutting speed, feed, depth of cut, and nose radius—four turning process variables that can be controlled—were investigated. For testing, a face-centred central composite design was used. Modelling the responses was done using the response surface methodology. The optimization of single (and multiple responses made use of the desirability function.

Interestingly, (Ashok et al., 2019; Bragadeshwaran et al., 2018, 2019; Dandajeh & Usman, n.d.; Kaisan, Anafi, et al., 2020; Kaisan et al., 2014, 2017, 2018, 2019; Kaisan, Yusuf, et al., 2020; Kaisan & Pam, 2013; Sani et al., 2018; Zare, Merajoddin, et al., 2012; Zare, Moosavi-Zare, et al., 2012; Zolfigol et al., 2017) worked on vegetable oil extraction, biodiesel production, characterizations with and without additives as well as engine and emission performance of the biodiesel sourced from bio based oils. Despite all the beautiful research that all this author did, to the best of my knowledge no work has been done on the development of cutting fluid using roselle oil as a coolant and determine the turning operation of lathe machine.

1.2. Materials and Methods

1.2.1 Raw Material

The material and equipment that were used for this study include.

i. Roselle oil
ii. Bright mild steel Work piece
iii. Titanium dioxide
iv. Hacksaw
v. Vanier scale
vi. Lathe machine (centre)
vii. High speed steel
viii. Stop watch
ix. Record sheet and pen
x. Universal grinding machine
xi. Laboratory balance
xii. Viscometer
xiii. Surface roughness tester*Section headings*

plate 1 Sample of Nano Fluids

1.3. *Preparation of Nano Fluid*

Roselle oil was obtained from. Titanium dioxide which was collected from physics department Ahmadu Bello University Zaria was used. With laboratory balance, the weight percentage 0.5 and 1 were obtained for the TiO2. Titanium dioxide in two different concentrations of 0.5 wt.% and 1wt.% were added to roselle oil and a magnetic stirrer was used to breakdown the agglomeration. To maintain further stability mechanical mixing was also carried out on Nanoparticles. Table 1 shows detail of the various Nano fluid prepared.

Table 1: Nano Coolant Formulation

SAMPLE NO	**BASE OIL**	**NANO PARTICLE**
1	100% Roselle oil	0 wt %
2	99.5% Roselle oil	0.5 wt %
3	90% Roselle oil	1 wt %

2. Analyses of the Fluid

2.1. Fourier Transform Infra-Red Spectroscopy (FTIR) Analyses of the Nano Coolant

FTIR Analysis or FTIR Spectroscopy, is an analytical technique used to identify organic, polymeric, and, in some cases, inorganic materials (Nkafamiya et al, 2017). The base sample was placed in the FTIR spectrometer. The spectrometer directs beams of IR at the sample and measures how much of the beam and at which frequencies the sample absorbs the infrared light. As the sample was placed directly into the infrared beam of the FTIR instrument, the IR passes through the sample and the transmitted energy was measured and a spectrum was generated. Each vibration will absorb specific wavelength of IR radiation which are shown as the reciprocal of the wavelength. The sample was thin enough so that the infrared light can transmit through. The reference data base houses thousands of spectra so the sample can be identified. This method was carried out for 0.5 and 1.0wt%. The Fourier transform spectrometer works to convert the raw data from the broad-band light source to actually obtain the absorbance level at each wavelength.1The sample test was taking at the chemistry laboratory.

2.2. *Viscosity Measurement*

The viscometer was placed in the 1000ml measuring cylinder filled to mark with water and regulated to the appropriate temperature. The tube was then filled up to a graduation mark over the left storage bulb with the base oil. The base oil was then sucked up to fill the higher storage bulb in the right left of the tube and then released. The time taken for the base oil to flow from the upper mark to the lower was observed and calculated. The kinematic viscosity of the biodiesel calculated using the formula below: The same procedure was repeated using 0.5wt% and 1.0w t%.

2.3 Basic Equations

The following relevant equations are useful in the machining operations.

$$\alpha + \beta + \gamma = 90 \quad (1)$$

$$Depth\ of\ cut, t = (d1 - d2) / 2 \quad (2)$$

$Where,$

$d1$=$Dia.\ of\ the\ work\ surf.\ before\ machining$

$d2$= $Dia.\ of\ the\ work\ surf.\ after\ machining$

$Kinematic\ viscosity$

η= $Absolute\ Viscosity\ (n)/density\ (p)$

$Absolute\ velocity\ (n) = (t - to)/to$

Where;

$t = time\ of\ flow\ of\ the\ sample$
$to = time\ of\ flow\ of\ the\ reference$

Fig. 1. FTIR Analyses Setup.

The turning operation was performed on a CNC lathe machine. The mild steel work piece having a diameter of 20mm measured using Vernier scale was mounted on the head stock of center lathe machine using jaw chuck a clamp used to hold an object with radial symmetry especially a cylinder. The work piece was then center drilled with a small drill spindle before the drilled hole was re-bored a drill of larger diameter. The high-speed steel cutting tool, 6° rake angle and 8° clearance angle were used to turn the work piece and the whole cutting process was cooled continuously with the coolant. The lathe machine was then powered up and as soon as the tool engaged the work piece and as cutting has almost started the stop watch was started. Each turning operation was performed for 5minutes on the overall length of the workpiece at various cutting speeds 80, 160 and 240 RPM. I selected the speeds because of the inbuilt speed offered by the lathe machine used for the experimentation. The test was conducted at constant feed rate of 0.3mm/rev, and also a constant dept of cut of 1.5mm.

2.3 Tool Wear Measurement

Tool wear was measured using the Dino-lite microscope. The Dino-lite is a hand held digital which is connected directly to the computer through a USB port. The device was placed in the stand and the magnification wheel which is accessible from the front with the lens and light pointing down at the base. The tool was placed on the base of the stand and position under the Dino-lite light. Using the large focus wheel to move the position of the L.E.D light the tool was focused, the Dino-lite was lowered to change the magnification by turning the wheel in front of the device. once the tool was focused, the angle of the wear was from the computer was taken. Click a small thumbnail of the image on the left of the image window to save. Tool wear was taken before and after machining of each work piece at the various speeds 80, 120 and 240rev/min.

2.4 Surface Roughness Measurement

Surface roughness measurements (Ra) value for each cutting condition were carried out with a surface roughness tester as shown in Figure 2b, which was taken at mechanical engineering department, Nigerian defense academy Kaduna with a stylus tip having radius 2 μm. The stylus tip made direct contact with the surface of the work piece, then the detector tip was equipped with a stylus tip, which traced the surface of the work piece and electrically detect the number of the stylus. The length tested for surface roughness tests was 3.2 mm in three sampling lengths of the work piece. To quantify the roughness, after each measurement the average value of roughness average (RA) was taken.

2.5 *Thickness and Chip Formation*

Chip thickness was also carried out using Dino-lite. After machining the chips were collected from each sample (0.5, 1.05 and base) at the various speeds 80,120 and 240rev/min. The chip was placed on the Dino-lite and the magnitude at 47.5 was used to find the length of the thickness. The length of each chip was taken 2 to 3 times and the average was taken. The type of chips formed was also captured and the type of chips was discussed.

3. Results and Discussion

3.1 *Nanofluid Stability*

The developed Nano fluids were evaluated for stability for 7 days post to the mechanical mixing and no sedimentation of the Nano particles was observed. Nano fluid stability plays a vital role in determining the properties. The Nano particles tend to form agglomerates and are prone to sedimentation due to various inter-particle forces. The various parameters such as Nano particle size, concentration and the methodology of Nano fluid preparation also affect the stability. The kinematic Viscosity were performed on the base oil. Table 4.1 shows viscosity of the sample. However, there is decrease in viscosity with the addition of TiO_2 Nano particles.

Table 2: viscosity results

S/N	Lubricants	Kinematic viscosity (m/s²)
1	Base oil	3.19
2	0.5%	2.88
3	1.0%	2.57

From the table 2 above it can be seen that the base oil has more viscosity than the Nano particles which flows easily and has a little friction when in motion compared to the virgin base oil.

3.2 FTIR Analysis

Below figure 4.1, figure 4.2 and figure 4.3 shows the wavelength and transmittance of the samples base oil, 0.5wt% and 1.0wt% respectively

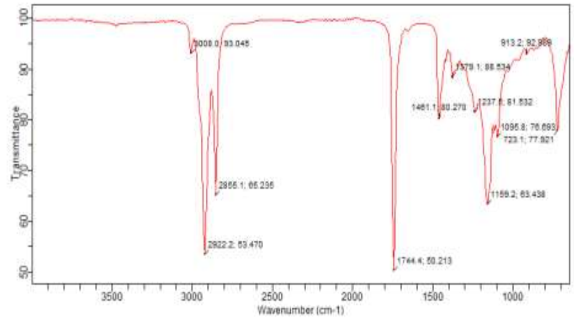


Figure 4.1Base oil wave transmittance

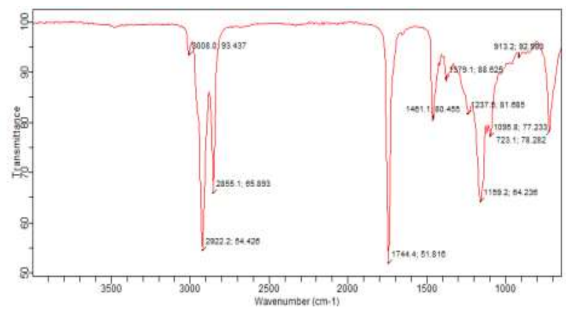


Figure4.2 0.5wt% wave transmittance

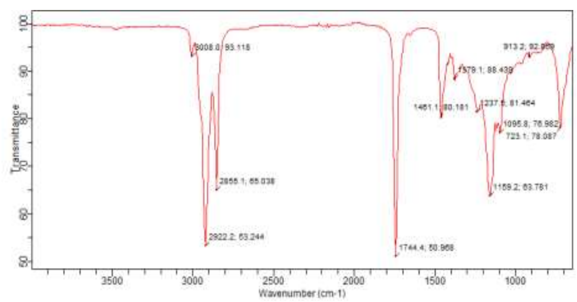


Figure 4.3 1.0wt% wave transmittance

From the figures above, it can be seen that the samples have the same wave numbers and almost the same transmittance. From the correlation table 4.2 below has two regions, the functional region from your right and the fingerprint region from your left. The fingerprint which starts from 1500cm-¹ can be identified because it has one functional group which are not very useful. The functional region which is above 1500cm-¹ Have various peaks and to understand IR we need to know what each peak is all about. From figure 4.1 it can be seen that at first peak 3008cm-¹ it has a functional group of carboxyl, hydroxyl which are acidic. The characteristics of carboxyl is their acidity and are generally more acidic than other organic compounds but are weaker than the familiar mineral acids eg hydrochloric acid, HCL etc. carboxyl occur widely in nature such as the fatty acids, hydroxyl acids such as lactic acid and citric acid are important metabolic product which exist in most living cells. At $2922.2cm^{-1}$ the functional group is amine, amides with N-H bond which are weak acids. At $2805.1cm^{-1}$ it has a functional group of alkanes which consist of a single bonded carbon and hydrogen. From $1500cm^{-1}$ wave number below may not have a useful functional group.

Table 2:Infra-red Spetropic Correlation Table

BOND	FUNCTIONAL GROUP	WAVE NUMBER (CM^{-1})
C-N	Not very useful	1000-1350
C-C	Aromatic compound, alkene	1500-1680
C-O	Amide carbonyl, carboxyl	1640-1690 1670-1740 1710-1750
C=N	Nitrile	2200-2250
N-H	Alkane	2800-2950
N-H	Amine, amide	3300-3500
O-H	Carboxyl, hydroxyl	2500-3100 3200-3600

3.3 Machining Behavior of Nano Fluids

3.3.1 Effect of Cutting Speed on Tool Wear

The table below shows the effect of cutting speed on tool wear at constant depth of cut and feed rate

Table 3: effect of cutting speed on tool wear

Nano particles	Depth of cut (mm)	Rake angle	Cutting speeds (rpm)	Length of wear (mm)
Base oil	1.5	80°	80	18.5
				18.8
				19.6
0.5wt%	1.5	80°	160	17.7
				18.3
				18.4
1.0wt%	1.5	80°	240	16.8
				16.2
				17.2

It can be observed that from figure 4.4, 4.5 and 4.6 that tool wear of HSS tool increases with an increase in cutting speed at constant depth of cut and feed rate using base oil lubricant. With further inclusion of Nano particle, it can be observed there is a decrease in wear at a concentration of 0.5wt% TiO_2 with an increase in cutting speed. The decrease is more significant at 1.0wt% of TiO_2 and even have a less wear at cutting speed of 160rev/min.

3.3.3 Effect of Cutting Speed on Surface Roughness

Table below shows the effect of cutting speed on tool wear at constant depth of cut and feed rate
Table 4.4 effect of cutting speed on surface roughness at 0.3mm feed rate

Nano Particle	Depth of Cut	Cutting Speed	Surface Roughness
Base	1.5	80	4.23
		180	5.86
		240	5.26
0.5WT%	1.5	80	3.16
		160	3.62
		240	2.52
1.0WT%	1.5	80	2.33
		160	1.70
		240	3.19

The surface roughness value is a measure of the quality of the machined surface achieved after machining the surface. Figure 4.5 below shows the effect of depth of cut at constant feed rate 0.3mm/rev. the case of base oil as the cutting speed increases from 80rev/min the RA value increases from 4.23nm to 5.86nm and reduces as the speed increases from 160rev/min to 240rev/min. with the addition of 0.5wt% of tio2 it reaches a maximum of up to 3.62nm and a minimum of 2.52nm. it was observed that 1.0wt% of tio2 at cutting speed of 160ev/min gives better surface finishing in comparison to other concentrations at all cutting speed.

3.3.4 Effect of Cutting Speed Against Chip Thickness

Table 4.5 effect of cutting speed against chip thickness

Nano particles	Depth of cut (mm)	Magnitude	Cutting speeds (rpm)	Chip thickness (mm)
Base oil	1.5	47.5	80	0.109
			160	0.11
			240	0.18
0.5wt%	1.5	47.5	80	0.080
			160	0.078
			240	0.11
1.0wt%	1.5	47.5	80	0.121
			160	0.16
			240	0.188

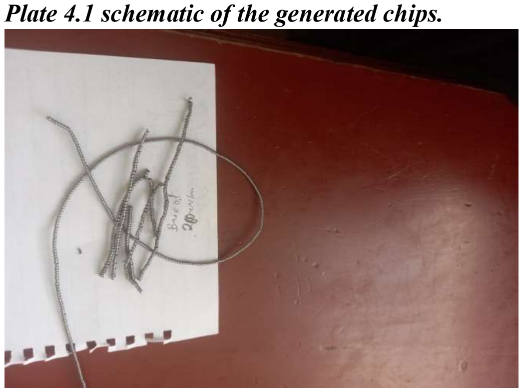
Figure 4.6 shows the effect of cutting speed on chip thickness at constant depth of and feed rate. It has been shown that with increase in cutting speed. The main variables affecting chip contractions are the cutting angle, the cutting speed, feed rate, depth of

cut, cutting fluid and the being machined. The base oil decreases in chip thickness from 80rev/min to 160rev/min then increases to a maximum at a cutting speed of 240rev/min. with the addition of Nano fluid at 0.5wt% the thickness was reduced further, at 160rev/min the thickness was reduced to a minimum and the chip is thinner compared to the other speeds and therefore gives the best chip compression. As the speed increases the thickness increases in the 1.0wt% of tio2 which produces the maximum chip compression.

3.3.5 Chip Formation

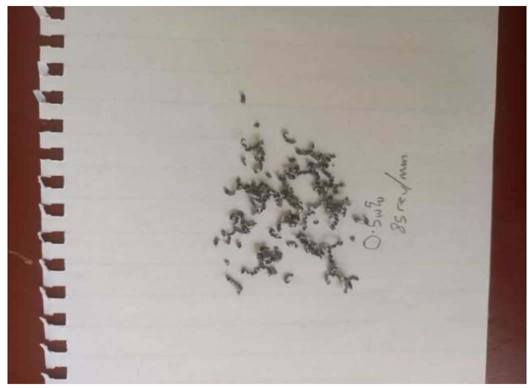
After each test each chip was collected and the representative images of the chips is shown in plate 4.1. The investigation shows that at low cutting speed there is no build up edge because a discontinuous chip was produce for base oil. As the cutting speed increases from 80rev/min to 240rev/min the chip changes to a continuous type and a lower helix angle was observed. A discontinuous was produced at a lower speed in 0.5wt% of TiO2 and at maximum speed of 240rev/min a larger angle of a continuous chip was produced with a better chip thickness obtained in the 0.5wt% TiO2.a ribbon type chip with saw tooth was produced in the 1.0wt% at the speed of 80rev/min and 160rev/min and a discontinuous chip produced at 240rev/min. 1.0wt% produces less chips than the other lubricants and this could be because the speed range for the investigation is not large enough.

Plate 4.1 schematic of the generated chips.

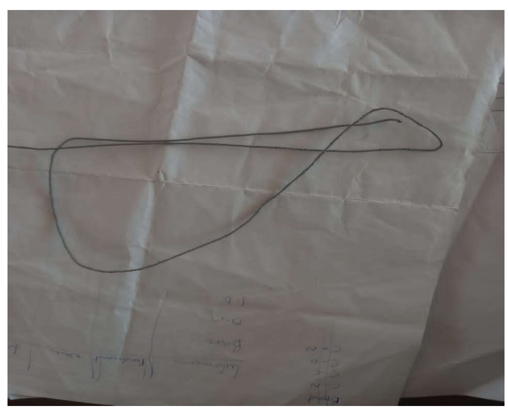


(a) Discontinuous chip at 80rpm of base oil

(b) continuous chip at base maximum



(c)Segmented chips at 0.5wt%



(d) Continuous chips at 0.5wt%

(e) Ribbon type chip with saw tooth at 1.0wt%

(f) Ribbon type chip with saw tooth at 1.0wt%

5. Conclusions

The present study investigates the effect of TiO_2 on the performance of bio-based roselle oil as a cutting fluid in turning operation. The following major conclusions were made:

i. Decrease in kinematic viscosity of the Nano fluid with an increase in concentration. (0.5wt% and 0.1wt %) of Nano particle as compared to the base oil was observed.
ii. Nano fluid corresponding to 1.0wt% tio2 exhibit improved result compared to 0.5wt% and base oil.
iii. Tool wear and surface finish is more improved with the addition of titanium dioxide in comparison to the base oil.
iv. Chip thickness, shape, and formation were observed with the particle suggesting their important role at the tool/work piece interface.
v. The FTIR analysis shows the properties of the bio-based roselle oil as a cutting fluid with the presence of fatty acid, carboxyl and amide which helps reduce surface roughness, friction and increase wetting oiliness.

5.2 Recommendation

This research shows the quality of roselle oil as a bio-based cutting fluid and with the presence of titanium dioxide Nano additive it enhances the performance further with improved surface finish, tool wear and even better chip formation and thickness. I recommend that other vegetable oils should be taking into consideration and with the presence of other Nano additives it can be used to check further the performance evaluation of this bio-based fluid and investigate other parameters such as temperatures and tool life which were not discussed in this research. I also recommend to try out other cutting speeds, depth of cut, feed rate and work piece.

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