International Journal of Materials Science and Applications
2024, Vol. 13, No. 5, pp. 91-100
https://doi.org/10.11648/j.ijmsa.20241305.12

Research Article

Wear Response of Aluminum Using a Mixture of Graphite and Snail Slime as Lubricant

Jude Ezechi Dara[1,*], Nelson Obinna Ubani[2], Anthony Amaechi Okafor[1], Emmanuel Chinagorom Nwadike[1]

[1]Department of Mechanical Engineering, Nnamdi Azikiwe University, Awka, Nigeria
[2]Department of Mechanical Engineering, Michael Okpala University of Agriculture, Umudika, Nigeria

Abstract

This study investigates the effects of a mixture of graphite and snail slime as a lubricant on the wear performance of aluminum. Environmental concerns associated with conventional lubricants have led to current attention on bio-based lubricants. Bio-based lubricants have several positive effects on the environment that include: biodegradability, lower carbon footprint, non-toxicity, and minimal waste generation. The current study considers the prospective of using snail slime as lubricants. The experimental setup involved subjecting aluminum samples to various wear tests, with the use of different graphite and snail slime mixture as lubricant. The wear test was done using a pin on disc tribometer, with aluminum as the pin. Through experimental testing and analysis, it was found that this mixture exhibits promising results in terms of reducing material loss, volume loss and wear rate in aluminum-based systems. Snail slime and graphite ratio of 2: 1 improves the lubricating effect of graphite by 89.84% with the application of 10 kg load. The results show that the wear resistance of aluminum significantly improves with the addition of the graphite and snail slime lubricant, compared to traditional lubricants. The incorporation of graphite and snail slime has shown to improve the lubricating properties of the graphite, thereby enhancing the performance of aluminum in various applications. This innovative lubricant has the potential to revolutionize the field of tribology and contribute to the development of more efficient and environmentally-friendly lubricants. Further research is required to fully understand the mechanism behind the improved lubrication and to optimize the composition of the mixture for different types of aluminum alloys. This study presents a novel and effective solution for improving the wear response of aluminum, making it a valuable contribution to the academic literature on tribology. The results of this research shed light on the potential of using unconventional lubricants, such as snail slime, to enhance the wear performance of aluminum in various applications.

Keywords

Wear Rate, Volume Loss, Material Loss, Snail Slime, Lubricant

1. Introduction

Most conventional lubricants are associated with environmental concerns making bio-lubricants viable alternatives with increasingly interests to researchers [1-4]. Bio-lubricants are biodegradable and environmental friendly while controlling friction, reducing wear and corrosion, and protecting the components' surface from excessive heat and debris. Mo-

*Corresponding author: je.dara@unizik.edu.ng (Jude Ezechi Dara)

Received: 16 August 2024; **Accepted:** 6 September 2024; **Published:** 20 September 2024

barak et al. [5] and Tuaweri and Ajoko [1] highlighted some of the benefits of using bio-lubricants as low toxicity, good anti-wear characteristics, excellent coefficient of friction, natural multi-grade properties, rapid biodegradability and emission of net zero greenhouse gases. Most studies on bio-lubricants centered on plant oils [5-9].

There are various species of snails in the world, with four being most prominent in Nigeria, namely; *Archachatina marginata* (suturalis), *Archachatina marginata* (ovum), *Achatina achatina*, and *Limcolaria spp* [10]. Snails and slugs are characterized by slimy trails of their slime left behind their path [11]. Snails secrete a certain slime whenever excited, and this slime is made up of glycoproteins [12]. Slime is produce by suprapedal glands and has the capacity to serve as moisturizer, lubricant and adhesive [13]. This hydrogel-like slime has increasingly been used for medical, cosmetic as well as bioengineering purposes. The medical aspect being that it aids the formation of collagen and elastin, repairs damaged tissues, restores hydration among many others [14]. It has been reported that slime contains ingredients that have therapeutic effects on human skin and has been used in cosmetic industries in the production of skin care creams [12, 14-16]. It can be used in treating dry skin, wrinkles and stretch marks, acne and rosacea, age spots, burns, scars and many more, including razor bumps. Moreover, it is useful as antibacterial, analgesic, and can be used in hemostasis [14]. Snail slime has been reported to have lubricating effect [12, 13, 17] and this natural property could be harnessed. Thus, with regard to bioengineering, the slime is of a slippery nature, and is also able to be used as a lubricant, as seen in snails themselves. Snails, in movement, secrete slime to reduce friction between them and the surface they move on, thus snail slime is in effect a lubricant, and may be useful in contact engineering.

Lubrication under dry condition is usually possible as a result of solid lubricants, which have low shear strength. Graphite, molybdenum disulfide and polytetrafluoroethylene are some common solid lubricants. Graphite has excellent lubrication characteristics when used as a solid lubricant [18]. About 3-4 wt % of graphite decreases the friction coefficient of copper–graphite composites from 0.92 to 0.29 and reduces the wear rate significantly [19]. Graphite-oil based nano-fluid improves the friction-reducing and anti-wear properties of vegetable based oil by forming a physical deposition film on the friction surfaces [20]. Tribological investigations of nano-lubricants reveal that nano-graphite-based nano-lubricant contributes about seven times improvement in the wear property and thirteen times amplification in the frictional property, compared to conventional base engine oil [21]. It has been reported that using graphite as filler material greatly enhances the tribological properties of the epoxy resin, by reducing the friction coefficient and the wear rate [22].

Most engineering applications involve the relative motion between contacting surfaces. The problem is the presence of excessive friction in such engineering activities which causes wear and damage of materials and equipment. Thus creating the need for the production of a better lubricant to aid in eliminating or reducing friction to the barest minimum. The aim of this study is to investigate the wear response of aluminum, using graphite and snail slime mixture as a lubricant.

2. Materials and Methods

Aluminum with a diameter of 8 mm and a length of 30 mm, 2.0 g of *Archachatina marginata* snail slime and 3 kg of graphite procured from Plateau State in Nigeria were used for the investigation. Methods employed for the data analyses and presentation are of three different categroies, there are: characterization of snail slime, characterization of crystalline graphite and wear test on crystalline graphite mixed with snail slime.

2.1. Characterization of Snail Slime

Gas Buck 530 gas chromatograph equipped with an on–column automatic injector was used in determining the organic compositions of the snail slime. 5ml of the extracted snail slime was mixed with 20ml of hexane. The mixture was agitated and separated using separating funnel and the hexane layer was used for the analysis. 1ml of hexane layer was transferred into a vial ready for analysis.

Also, the inorganic compositions of the snail slime analysis was conducted using Varian AA240 Atomic Absorption Spectrometer. A series of standard metal solutions in the optimum concentration range was prepared, the reference solutions were prepared by diluting the single stock element solutions with water containing 1.5ml concentrated nitric acid/litre. A calibration blank was prepared using all the reagents except for the metal stock solutions. Calibration curve for each metal was prepared by plotting the absorbance of standards versus their concentrations.

2.2. Characterization of Crystalline Graphite

The graphite was ground into tiny particles using a ball mill, and 10 g of graphite was weighed out with the Toolour E-100 weighing scale. The mineral content was determined using the Shimadzu x-ray fluorescence analyzer EDX-720. The graphite sample was fed into the inlet compartment for radiation. As the graphite sample was radiated, the excited electrons lost excitement and released the absorbed radiation. The unique wavelengths of the rays released were observed and the mineral contents were thus determine. The XRF analysis was run twice, over a total period of 100 seconds, and the XRF was fed with a voltage of 40 KV and a current of 50 mA.

2.3. Wear Test on Crystalline Graphite Mixed with Snail Slime

The aluminium was heated to a temperature of 700 ℃ in a gas furnace, past its melting point of 660℃ to prevent immediate re-solidifying upon extraction. The melted aluminium was then poured into the mould shaped as the pin with a diameter of 8 mm and a length of 30 mm, and allowed to solidified in ambient temperture. The pin-shaped aluminium was inserted as the pin in the Fadak pin-on-disc tribometer.

Snail slime was extracted by passing a low voltage through the sample snails, producing 3 g of snail slime. The ground graphite and the extracted snail slime were mixed in different proportions. The mixture was stirred rigorously to obtain a homogenous mixture. This graphite-slime mixture was overlaid on the disc of the tribometer, and varying loads were applied on the aluminium pin during the experiments, keeping the pin in constant contact with the disc. The eight samples used in the experimental runs were described in table 1. Table 2 presented the input parameters for the wear test.

Table 1*. Description of samples.*

Sample	Description
A	The control test without any lubricant
B	0.5 g of snail slime only used as lubricant
C	0.5 g of graphite only used as lubricant
D1	0.5 g of snail slime mixed with 0.05 g of graphite
D2	0.5 g of snail slime mixed with 0.10 g of graphite
D3	0.5 g of snail slime mixed with 0.15 g of graphite
D4	0.5 g of snail slime mixed with 0.20 g of graphite
D5	0.5 g of snail slime mixed with 0.25 g of graphite

Table 2*. Input parameters for the wear test.*

Sample	Load (kg)	Speed (rev/min)	Time (sec)	Distance (m)
A	2	1400	90.47	530.154
	5	1400	180.65	1058.609
	10	1400	179.29	1050.639
B	2	1400	90.49	530.271
	5	1400	180.64	1058.550
	10	1400	179.35	1050.991
C	2	1400	90.43	529.920
	5	1400	180.69	1058.843
	10	1400	179.29	1050.639
D1	2	1400	90.44	529.978
	5	1400	180.58	1058.199
	10	1400	179.38	1051.167
D2	2	1400	90.48	530.213
	5	1400	180.65	1058.609
	10	1400	179.23	1050.288
D3	2	1400	90.49	530.271
	5	1400	180.23	1056.148
	10	1400	180.30	1056.558

Sample	Load (kg)	Speed (rev/min)	Time (sec)	Distance (m)
D4	2	1400	90.22	528.689
	5	1400	180.31	1056.617
	10	1400	179.30	1050.698
D5	2	1400	90.25	528.865
	5	1400	180.47	1057.554
	10	1400	180.12	1055.503

There were eight samples used in the twenty four tribological tests, running three tests per sample at different loads, and three tests for the control test. The samples were placed at a radius of 40 mm from the centre of the disc, and the pin was set to make contact at the same distance from the centre. All tests were conducted at a rotational speed of 1400 rpm, and the wear of the aluminium pin was observed by the continual weighing of the pin. The three loads used were 2 kg, 5 kg and 10 kg. The 2 kg were tested for a duration of roughly 90 seconds, and the 5 kg and 10 kg loads were tested for durations of roughly 180. Basically, the amount of wear of the aluminum pin was measured, as the aluminum pin was weighed before and after each experiment. The most wear was experienced in the control test which had neither snail slime nor graphite as a lubricant.

3. Results and Discussion

3.1. Gas Chromatograph Analysis of Organic Metals of Snail Slime

Gas chromatograph test conducted on the snail slime revealed that about twelve organic compound are present in the snail slime as indicated in table 3. The organic components comprise of long linear chains and benzenoic chains. Notable among the component is octadecane used as solvent, lubricant, transformer oil and anti-corrosion agent. Moreover, diethyl phthalate is used as a plasticizer in a wide variety of consumer products, including plastic packaging films, cosmetic formulations and toilrtries, as well as in medical treatment tubing. Cyclotrisiloxane hexamethyl an organosilicon compound with single bond aromatic ring has an excellent moisturizing property and has been reported as one of the major compounds in essential oil of sedum pallidum [23].

Table 3. *Organic Components of Sample Snail Slime.*

Component	Retention	Area	Height	External	Units
Oxime-methoxy-phenyl	1.883	3733.4476	212.018	8.4108	Ppm
Cyclo-trisiloxanehexamethyl	4.596	3462.5282	210.938	2.0044	µg/ml
Hexadecane	8.746	17782.1411	968.052	11.7090	Ppm
Diethyl phthalate	12.666	6589.1400	373.983	2.4256	µg/ml
10-methylnonadecane	15.696	15646.2445	872.729	13.5857	µg/ml
Pentadecane	18.260	10783.8175	578.227	15.6016	µg/ml
Hexatriacontane	24.106	4628.3302	262.965	5.5363	µg/ml
1-2-Benzene dicarboxylic acid	29.116	17749.1294	994.076	10.2745	Ppm
Vitamin C	31.413	8523.0996	483.918	5.6122	mg/ml
Tetradecane	32.353	13097.7557	739.537	2.0231	Ppm
Nonadecane	39.246	5361.1156	304.460	0.9534	Ppm
Octadecane	45.350	8269.4048	477.570	3.6309	Ppm

3.2. Atomic Absorption Spectrometer Analysis

An atomic absorption spectrometer was used to investigate the inorganic components of the snail slime. The snail slime was found to contain the following elements; zinc, iron, manganese, calcium, molybdenum, sodium, potassium, phosphorus, silicon, magnesium, carbon and oxygen. Table 4 shows the various inorganic components found in snail slime and their compositions.

***Table 4**. Inorganic components of snail slime.*

Element	Composition	Unit
Zinc	0.024	Ppm
Iron	0.272	Ppm
Manganese	0.088	Ppm
Calcium	1.834	Ppm
Molybdenum	0.305	Ppm
Sodium	6.372	Ppm
Phosphorus	0.834	mg/l
Potassium	7.082	Ppm
Silicon	0.00	Ppm
Magnesium	2.878	Ppm
Carbon	0.147	%
Oxygen	50	mg/kg

Phosphorus at high temperatures of about 200 ℃, can be converted to a flaky black crystalline form which somewhat resembles graphite, and is the most stable known form of phosphorus. This temperature can be achieved during some activities involving friction, and the graphite-like state which is the most desirable state of phosphorus is attained. Additionally, due to the electronic configuration of phosphorus, phosphorus forms covalent bonds. The outer shell arrangement containing five electrons has three half-filled orbitals, each capable of forming a single covalent bond and an additional lone pair of electrons. The single standing electrons form covalent bonds, and as such can give it an oxidation state of +3 or -3. Oxygen is also present among the constituents of the snail slime sample. It plays an important role in the slimy nature of snail slime, aiding the formation of glycoproteins. Phosphorus calcium, and zinc have been identified as major additives in virgin lubricating oils [24].

Carbon is known to bond commonly with nitrogen, oxygen and phosphorus. Graphite however bonds under special conditions. For a graphite bond with oxygen. The graphite needs to have attained a high enough temperature of roughly 400°C. It plays an important role in the slimy nature of snail slime, aiding the formation of glycoproteins. Carbon also bonds with silicon which is of a similar composition, having the same number of electrons in the outer shell, but a greater number of shells. But graphite bonds mainly in high heat conditions. However, oxidized graphite can be decomposed thermally or electrically, but since friction has minimal activity to do pertaining electricity, the main concern is the thermal decomposition of graphite oxide. Graphite gets reduced when subjected to annealing (great heating, then slow cooling) in the presence of nitrogen. But the magnitude of nitrogen present is not enough to have this effect, neither is the heat generated in the lubricating process enough.

3.3. X-ray Fluorescence on Graphite

A sample of graphite was tested for its mineral content using the XRF analysis and seven components were found as seen in figure 1

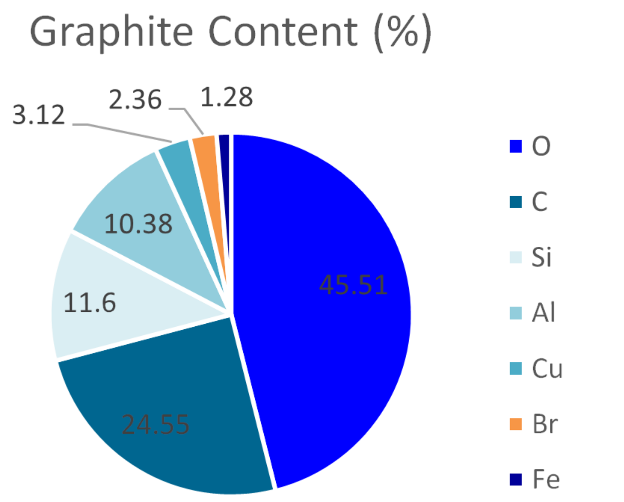

***Figure 1**. Pie chart representing atomic components of graphite.*

The elements detected in the graphite are oxygen making up 45.51% of the graphite, carbon at 24.55%, silicon at 11.6%, aluminium at 10.38%, copper at 3.12%, bromine at 2.36% and iron being the least present at 1.28%.

3.4. Tribology of Graphite-Slime Mixture

The results of the wear tests are presented in Table 5.

Table 5. *Wear test results.*

Sample	Weight before (g)	Weight after (g)	Weight loss (g)	Volume loss (m^3)	Wear rate (mm^3/N-m) x10^{-7}
	8.385	8.373	0.012	4.4444	4.2728
A	8.373	8.361	0.012	4.4444	0.8559
	8.361	8.312	0.049	18.1482	1.7608
	8.336	8.331	0.005	1.8519	1.7800
B	8.331	8.326	0.005	1.8519	0.3567
	8.326	8.316	0.010	3.7037	0.35923
	8.219	8.210	0.009	3.3333	3.2060
C	8.210	8.180	0.030	11.1111	2.1394
	8.180	8.162	0.018	6.6667	0.6468
	8.384	8.377	0.007	2.5926	2.4933
D1	8.377	8.362	0.015	5.5556	1.0703
	8.362	8.350	0.012	4.4444	0.4310
	8.324	8.324	0.000	0	0
D2	8.324	8.322	0.002	0.7407	0.1427
	8.322	8.309	0.013	4.8148	0.4673
	8.363	8.363	0.000	0	0
D3	8.363	8.363	0.000	0	0
	8.363	8.352	0.011	4.0741	0.3931
	8.319	8.319	0.000	0	0
D4	8.319	8.319	0.000	0	0
	8.319	8.310	0.009	3.3333	0.3234
	8.263	8.263	0.000	0	0
D5	8.263	8.263	0.000	0	0
	8.263	8.258	0.005	1.8519	0.1788

For the control (sample A), the pin reduce from a weight of 8.385 g to a weight of 8.373 g with the application of 2 kg load. The pin was then observed to reduce from the weight of 8.373 g to the weight of 8.361 g after 180.65 seconds with application of 5 kg load. Finally, after 179.29 seconds with application of 10 kg load, the weight was reduced from 8.361 g to 8.312 g. There was a total weight loss of 0.073 g.

Consequently, the wear test was performed on sample B, showed that the pin reduce from a weight of 8.336 g to a weight of 8.331 g, giving a weight loss of 0.005 g due to wear after 90.49 seconds of applying 2 kg load. The pin was then observed to reduce from the weight of 8.331 g to the weight of 8.326 g, producing a weight loss of 0.005 g due to wear after 180.64 seconds of application of 5 kg load. Finally, after 179.35 seconds of application of 10 kg load, the weight reduced from 8.326 g to 8.316 g, with a weight loss of 0.01 g. The total weight loss for sample B was 0.02 g. Thus, there was less wearing of sample B than observed in the control sample.

Moreover, the wear test performed on sample C showed the the pin reduce from a weight of 8.219 g to a weight of 8.210 g, with a weight loss of 0.009 g after 90.43 seconds of applying 2 kg load. The pin was then observed to reduce from the weight of 8.210 g to the weight of 8.180 g, giving a weight loss of 0.030 g after 180.69 seconds of application of 5 kg load. Finally, after 179.29 seconds of application of 10 kg load, the weight reduced from 8.180 g to 8.162 g, with a weight loss of 0.018 g. The total weight loss obersved with sample C was 0.057 g. This showed more weight loss than using only snail slime as lubricant. In essence, though graphite has a lubricating effect, snail slime seems to reduce wearing of aluminum better.

Considering sample D1, the aluminum pin was noticed to reduce from a weight of 8.384 g to a weight of 8.377 g, with a weight loss of 0.007 g after 90.44 seconds of applying 2 kg load. The pin was then observed to reduce from the weight of 8.377 g to the weight of 8.362 g, producing a weight loss of 0.015 g after 180.58 seconds of application of 5 kg load. Conversely, with application of 10 kg load at 179.38 seconds, the weight was reduced from 8.377 g to 8.350 g, with a weight loss of 0.027 g. The total weight loss experienced by the aluminum pin with the mixture of 0.05 g of graphite and 0.5 g of snail slime was 0.034 g. This was an improvement on using only graphite as lubricant.

The wear test was performed on sample D2 indicated that the pin maintain the weight of 8.324 g after 90.48 seconds of applying the load of 2 kg. The pin was then observed to reduce from the weight of 8.324 g to the weight of 8.322 g, producing a weight loss of 0.002 g after 180.65 seconds of applying 5 kg load. The application of the 10 kg load for 179.23 seconds led to reduction of weight from 8.322 g to 8.309 g, with a loss of 0.013 g. There was a total weight loss of 0.015 g. This ratio of snail slime to graphite has therefore proven to be a better lubricant than snail slime alone, in that lost of material to wear was less.

The result of the wear test performed on sample D3 showed that the pin did not loss any weight when a load of 2 kg was applied for 90.49 seconds. The pin did not even reduce in weight with the application of 5 kg load for 180.23 seconds. It maintained its weight of 8.363 g after of application 5 kg load. But with the application of the 10 kg load for 180.30 seconds the weight was reduced from 8.363 g to 8.352 g, with a weight loss of 0.011 g. Therefore, the mixture of 0.5 g of snail slime with 0.15 g of graphite proved to be an efficient wear reduction medium. It recorded only a total wear lost of 0.011 g which is less when compared with when either snail slime or graphite is used alone.

The wear test performed on sample D4 revealed that the pin did not wear out when loads of 2 kg and 5 kg were apllied for 90.22 seconds and 180.31 seconds respectively. Nevertheless, it lost a weight of 0.009 when a load of 10 kg load was applied for 179.30 seconds. It implies that the mixture of 0.5 g of snail slime with 0.20 g of graphite exhibited an excellent lubrication ability. The mixture performed better than using the lubricants independently.

The wear test performed on sample D5, having 0.5 g of snail slime mixed with 0.25 g of graphite showed that the pin maintained its weight of 8.263 g with the application of 2 kg and 5 kg load for 90.25 seconds and 180.47 seconds respectively. The appplication of 10 kg load for 180.12 seconds led to weight reduction from 8.263 g to 8.258 g, with a weight loss of 0.005 g. Hence, the total weight loss was 0.005 g signifying that the ratio of 0.5 g of snail slime to 0.25 g proved to be the most efficient in wear prevention than the previous tests, with a negligible wear. In general, there was a noticeable trend in wear rate being directly proportional to graphite quantity in the mixture, with an exception of sample D1, and there was also visible wear prevention, or minimal wear, under conditions of low load. The respective total weight lost in each of the eight lubrication conditions are represented in Figure 2 with the most weight loss occurring in sample A and the least weight loss is associated with sample D5. Therefore, mixing graphite with snail slime reduces material loss due to wear in aluminum surface contact.

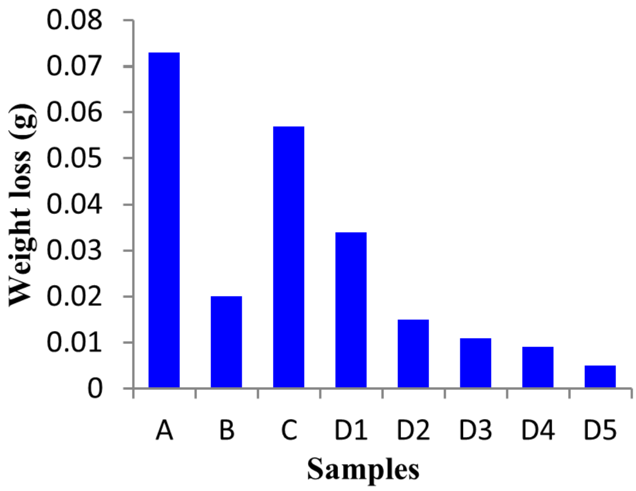

Figure 2. *Plot representing total weight loss by the samples.*

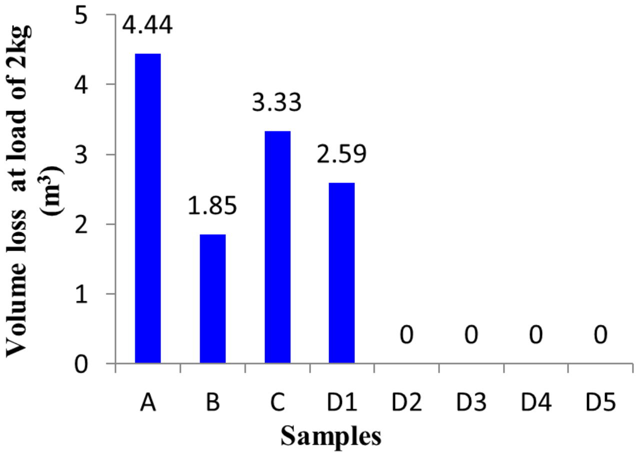

Figure 3. *Volume loss by the samples with application of 2 kg load.*

The volume lost by the samples due to the applications of various loads are presented in figures 3 to 5. The volume loss was evaluated using equation 1. The loss of volume due to the application 2 kg load is illustrated in figure 3. It was found that the most volume loss of 4.44 m^3 was due to wear in the experimental run with sample A, followed by the run with sample C, where a volume of 3.33 m^3 was lost. Sample B recorded the lowest volume loss of 1.85 m^3. Samples D2, D3, D4 and D5 recorded negligible volume losses indicating that at lower loading, the mixture of graphite and snail slime has the capacity to serve as a good lubricant.

$$\Delta V = \frac{\Delta w}{\rho} \times 1000 \quad (1)$$

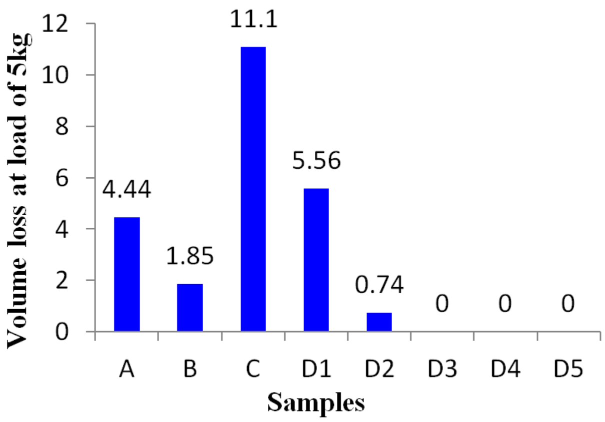

Figure 4. *Volume loss by the samples with application of 5 kg load.*

The volume loss due to the application of 5 kg load was illustrated in figure 4. It was found that sample C lost most volume (11.1 m^3) due to wear, followed by the run with sample D1 that lost a volume of 5.56 m^3. Sample D2 recorded least volume loss of 0.74 m^3 while and samples D3, D4, and D5 recorded no volume loss. It implies that at moderate load of 5 kg, samples having 0.5 g of snail slime with 0.15 g of graphite, 0.5 g of snail slime with 0.20 g of graphite and 0.5 g of snail slime mixed with 0.25 g of graphite gave excellent wear resistance.

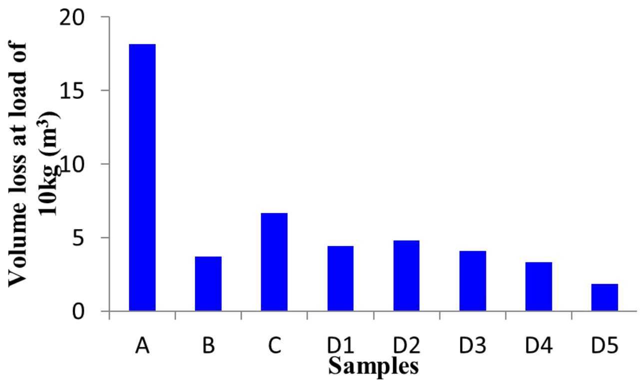

Figure 5. *Volume loss by the samples with application of 10 kg load.*

The loss of volume by the samples with application of 10 kg load was illustrated in figure 5. It was found that the most volume was lost due to wear in the experimental run with sample A, followed by the run with sample C, the run with sample D2, the run with sample D1, the run with sample D3, the run with sample B, the run with sample D4 and finally the least volume loss was seen in the run with sample D5. All the samples recorded volume lost with the application of 10 kg load, though sample D5, 0.5 g of snail slime mixed with 0.25 g of graphite, exhibited reasonable wear resistance. The combination of graphite and snail slime improves the lubricating capability of graphite and reduces the volume loss by contacting members.

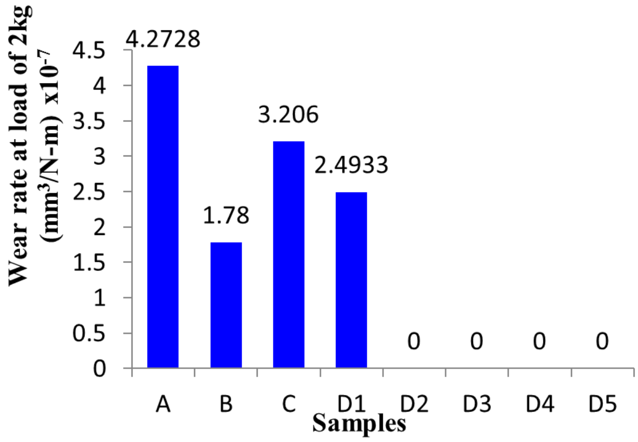

Figure 6. *Plot of wear rate at load of 2 kg.*

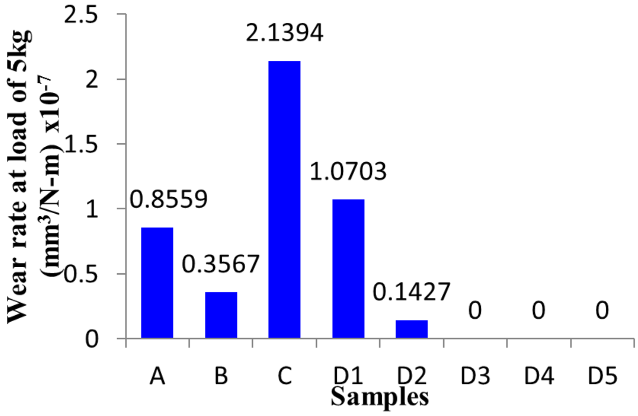

Figure 7. *Plot of wear rate at load of 5 kg.*

Figure 6 depicted the wear rates of the samples due to the application of 2 kg load. The wear rate is computed using equation 2 [25]. It was found that the highest wear rate of 4.27 X 10^{-7} mm^3/N-m is associated with sample A being the control sample without any lubricant. Sample C, having 0.5 g of graphite only as lubricant that recorded wear rate of 3.206 X 10^{-7} mm^3/N-m. Sample D1, having 0.5 g of snail slime mixed with 0.05 g of graphite recorded wear rate of 2.49 X 10^{-7} mm^3/N-m, while sample B with 0.5 g of snail slime only as lubricant had the least wear rate of 1.78 mm^3/Nm. Samples D2, D3, D4, and D5 recorded zero wear rate.

$$W = \frac{\Delta w}{\rho \times v \times t \times F} \tag{2}$$

Figure 7 represented the wear rates as evaluated for 5 kg loading for the eight samples. It was found that the highest wear rate is associated with sample C, followed by sample D1, sample A, sample B and finally sample D2, with the rest of the samples having negligible wear rates.

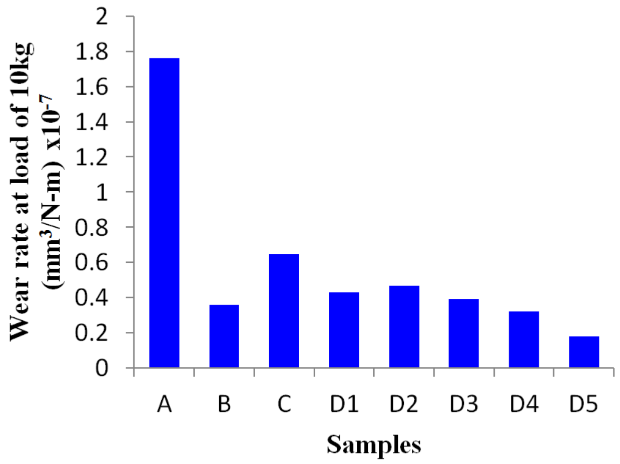

Figure 8. *Plot of wear rate at load of 10 kg.*

Figure 8 represents the wear rates of 10 kg loading for the eight samples. It could be observed that the highest wear rate of 1.76 X 10^{-7} mm^3/N-m is associated with sample A, being the control sample without any lubricant. It is followed by sample C, having 0.5 g of graphite only as lubricant that recorded wear rate of 0.65 X 10^{-7} mm^3/N-m while sample D5, having 0.5 g of snail slime mixed with 0.25 g of graphite recorded the least wear rate of 0.1788 X 10^{-7} mm^3/N-m. It could be seen that as load increases, graphite lubricating prowess decreases; but it could be enhanced by adding snail slime. The addition of 0.5 g of snail slime to 0.25 g of graphite, that is snail slime and graphite ratio of 2: 1 improves the lubricating effect of graphite by 89.84%.

Experimental runs with application of 2 kg load revealed that sample A experienced the highest wear rate of 4.2728 X 10^{-7} mm^3/N-m. Whereas in the experimental runs with application 5 kg load, sample C recorded the highest wear rate of 2.1394 X 10^{-7} mm^3/N-m. Finally, with application of 10 kg load, sample A experienced the highest wear rate of 1.7608 X 10^{-7} mm^3/N-m. It implies that at moderate loading, graphite can serve as a good lubricant but at low and high loadings, the addition of snail slime might be needed to reduce the effects of wear to as low as practically possible.

4. Conclusions

This work considered with the development of improved lubricant (graphite-slime mixture), for the solution of the persistent problem of wear due to relative moving members. It was found that there was more evident of wear in the control sample without any lubricant compared to the slime-only, graphite-only, and graphite-slime scenarios. It was also found that there was more evident of wear in the graphite-only scenario than in the slime-only, indicating that snail slime is natural lubricant containing octadecane, phosporous, and carbon with other components. It was found that the wear was greatly reduced by graphite-slime mixture. Snail slime and graphite ratio of 2:1 improves the lubricating effect of graphite by 89.84% with the application of 10 kg load. Thus, the graphite-slime mixture is a viable lubricant, with a higher lubricity and lower wear rate.

Abbreviations

F	Force (N)
t	Time (sec)
ρ	Density (g/cm^3)
v	Velocity (m/s)
W	Wear Rate (mm^3/N-m)
ΔV	Volume Loss (m^3)
Δw	Change in Weight (g)
ΔV	Volume Loss (m^3)

Author Contributions

Jude Ezechi Dara: Conceptualization, Investigation, Writing original draft

Nelson Obinna Ubani: Resources, Writing review & editing

Anthony Amaechi Okafor: Methodology, Formal Analysis

Emmanuel Chinagorom Nwadike: Conceptualization, Resources

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Tuaweri T. J. and Ajoko T. J. Comparative Analysis of the Friction Characteristics of Graphite enhanced Biolubricants and SAE20W40 Engine Oil, International Journal of Academic Engineering Research (IJAER), 2018, 2(3): 1-6. http://ijeais.org ›2018/03 ›IJAER180301

[2] Okfor Anthony Amaechi and Mgbemena Chinedum Ogonna Preparation of Hybrid Nanofluids, Their Thermophysical Properties, and Stability Parameters, Journal of Engineering Physics and Thermophysics, 2022, Volume 95, Issue 2, p. 533-538. https://doi.org/10.1007/s10891-022-02509-8

[3] Okafor, Anthony Amaechi; Mgbemena, Chinedum Ogonna; Oreko, Benjamin Ufuoma. Preparation, Characterization, Stability and Thermophysical Properties of Bio, Non-Bio (Metallic and Non-Metallic) and Hybrids Nanofluids: A Review, Journal of Nanofluids, 2022, 11(6): 803-818. https://doi.org/10.1166/jon.2022.1896

[4] Okafor A. A., Dara J. E., Okafor L. U., Ilechukwu A. E and Ezenwa N. O. Effects of nanoparticles volume fractions on the viscosity of nanofluids prepared from palm kernel shell nanoparticles, Unizik Journal of Technology, Production and Mechanical Systems (UJTPMS), 2024, 3(1): 111-115. https://journals.unizik.edu.ng/ujtpms/article/view/3591/2909

[5] Mobarak, H. M., Mohammad, E. N., Masjuki, H. H., Kalam M. A., Mahmud, K. A. H., Habibullah, M., Ashraful, A. M., The prospects of biolubricants as alternatives to automotive applications. Renewable and Sustainable Energy Reviews, 2014, 33, 34-43. https://doi.org/10.1016/j.rser.2014.01.062

[6] Arwin, G. Z., Rashmi, G. W., Tribological Evaluation of Nano Graphene Platelets as an Additive to Biolubricant base Fluid. EURECA Conference March 2013.

[7] Salih, N., Salimon, J, and Jantan, F. N., Synthesis and Characterisation of Palm Kernel Oil Based Trimethylolpropane Ester, Asian Journal of Chemistry, 2013, 25(17): 9751-9754. https://doi.org/10.14233/ajchem.2013.15299

[8] Akobuche C. W., Ossia C. V., "Enhancing the Tribological Properties of Biodegradable Oils by Organic Additives under Extreme Conditions", Jurnal Tribologi – A journal of the Malaysian Society of Tribologists, 2018, 19, 1-18. https://api.semanticscholar.org/CorpusID:220332071

[9] Eziwhuo J., Ossia, C. V., Alibi S. I., "Evaluation of Apricot kernel, Avocado and African pear seed oils as Vegetable-based cutting fluids in turning AISI 1020 steels", IOSR Journal of Engineering, 2019, Vol. 9(3) (S-1): 10-192, https://iosrjen.org/Papers/vol9_issue3/Series-1/B0903011019.pdf

[10] Fagbuaro O., Oso J. A., Edward J. B., and Ogunlere R. F. Nutritional Status of Four Species of Giant Land Snails in Nigeria. Journal of Zhejiang University Science B, 2006, 7(9): 686-689; https://doi.org/10.1631/jzus.2006.B0686.

[11] Pradeep Kumar. A Review - On Molluscs as an Agricultural Pest and Their Control, *International Journal of the Science of Food and Agriculture*, 2020, 4(4): 383-389. https://doi.org/10.26855/ijfsa.2020.12.004

[12] Greistorfer S., Klepal W., Cyran N., Gugumuck A., Rudoll L., Suppan J. and von Byern J. Snail mucus-glandular origin and composition in Helix pomatia, *Zoology*, 2017, 122: 126–138. https://doi.org/10.1016/j.zool.2017.05.001

[13] Trapella Claudio, Rizzo Roberta, Gallo Stefania, Alogna Andrea, Bortolott Daria, Casciano Fabio, Zauli Giorgio, Secchiero Paola and Voltan Rebecca, HelixComplex snail mucus exhibits pro-survival, proliferative and pro-migration effects on mammalian fibroblasts, Scientific Reports 8, 17665, 2018, https://doi.org/10.1038/s41598-018-35816-3

[14] Harti Agnes Sri, Murharyati Atiek, Sulisetyawati Dwi S. and Oktariani Meri, The effectiveness of snail mucus (achatina fulica) and chitosan toward limfosit proliferation in vitro. *Asian Journal of Pharmaceutical and Clinical Research* 11(3): 2018, 85-88 https://doi.org/10.22159/ajpcr.2018.v11s3.30041

[15] El Mubarak M. A. S., Lamari F. N., Kontoyannis C. Simultaneous determination of allantoin and glycolic acid in snail mucus and cosmetic creams with high performance liquid chromatography and ultraviolet detection, *Journal of Chromatography A*, 2013, 1322: 49-53. https://doi.org/10.1016/j.chroma.2013.10.086

[16] Harti A. S., Sulisetyawati S. D., Murharyati Atiek A., Oktariani M. and Wijayanti I. B. The effectiveness of snail slime and chitosan in wound healing, *International Journal of Pharma Medicine and Biological Sciences*, 2016, 5(1): 76-80. https://doi.org/10.18178/ijpmbs.5.1.76-80

[17] Denny M. *Molecular biomechanics of molluscan mucous secretions*. In: Hochachka P. W. (ed) *The Mollusca – Metabolic Biochemistry and Molecular Biomechanics*, 1st edition, Academic Press, New York: 1983, pp 431–465. https://doi.org/10.1016/B978-0-12-751401-7.50017-X

[18] Lee, C.-G., Hwang, Y.-J., Choi, Y.-M., Lee, J.-K., Choi, C., & Oh, J.-M. A study on the tribological characteristics of graphite nano lubricants. International Journal of Precision Engineering and Manufacturing, 2009, 10(1), 85–90. https://doi.org/10.1007/s12541-009-0013-4

[19] Qian Liu, Miguel Castillo-Rodríguez, Antonio Julio Galisteo, Roberto Guzmán de Villoria, and José Manuel Torralba, Wear Behavior of Copper–Graphite Composites, Processed by Field-Assisted Hot Pressing, Journal of Composites Science, 2019, 3, 29: 1-11; https://doi.org/10.3390/jcs3010029

[20] Yu Su, Le Gong, and Dandan Chen, An Investigation on Tribological Properties and Lubrication Mechanism of Graphite Nanoparticles as Vegetable Based Oil Additive, Journal of Nanomaterials Volume 2015, Article ID 276753, 7 pages http://dx.doi.org/10.1155/2015/276753

[21] Singh Jyoti Prakash, Singh Shiva, Nandi Tandra, Ghosh Subrata Kumar, Development of graphitic lubricant nanoparticles based nanolubricant for automotive applications: Thermophysical and tribological properties followed by IC engine performance, *Powder Technology*, 2021, 387, 31–47. https://doi.org/10.1016/j.powtec.2021.04.010

[22] Sakka M. M., Antar Z., Elleuch K., Feller J. F. Tribological response of an epoxy matrix filled with graphite and/or carbon nanotubes, *Friction, 2017,* 5(2): 171–182 https://doi.org/10.1007/s40544-017-0144-z

[23] Dahpour A. A., Rahdari P. and Sobati Z. Chemical composition of essential oil, antibacterial activity and brine shrimp lethality of ethanol extracts from Sedum pallidum, *Journal of Medicinal Plants Research*, 2012, 6(16): 3105-3109. https://doi.org/10.5897/JMPR11.1270

[24] Munirah Abdul Zali, Wan K. Wan Ahmad, Ananthy Retnam and Ng Catrina (2015) Concentration of heavy metals in virgin, used, recovered and waste oil: a spectroscopic study, *Procedia Environmental Sciences*, 2015, 30: 201 – 204 https://doi.org/10.1016/j.proenv.2015.10.036

[25] Gangwar, S., Patnaik, A., & Bhat, I. Tribological and thermomechanical analysis of CaO (quicklime) particulates filled ZA-27 alloy composites for bearing application. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 2015, 232(1), 20–34. https://doi.org/10.1177/1464420715609196