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Formulation Ratio Effectiveness of Green Metal Working Fluid (GMWF) as a Bio Alternative for Green Manufacturing

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Abstract: *Metalworking fluid (MWF) is essential for ensuring quality products and extended tool life during machining operations. While there are various sources of MWF, the need to minimize health hazards associated with mineral-based metal-working fluid now calls for more environmentally friendly green metal–working fluid (GMWF) from bio-degradable sources. Also, the effectiveness of vegetable-based GMWF significantly depends on the degree of functionalization. Though some studies considered the issue, the comparative analysis of the effect formulations (variation in concentration) of the constituting elements of the GMWF, especially for the base vegetable oil under consideration; has been grossly underreported. In this study, a GMWF emulsion has been developed from soybeans, palm fruits, and coconut with varying formulation ratios. Physicochemical characterization such as flash point, fire point, pour point, pH, density, and viscosity of the developed GMWF were analyzed. Also, a performance evaluation of the said GMWF was carried out and the investigation has shown that the physicochemical properties of the developed GMWF matched, as a potential substitute for conventional mineral-based MWF. Additionally, a performance evaluation conducted during a mechanical machining operation revealed that the GMWF showed an improved surface roughness of about 10.77% compared to conventional mineral MWF. Observations during the machining operation further revealed that the formulated GMWF demonstrated some level of environmental tolerance as it was not associated with misting or the discharge of fumes. The research outcome will impact green machining science and MWF technology for sustainable mechanical machining and cutting fluid development.*

Keywords: *Green Manufacturing, Machining, Cutting Fluids, Vegetable Oil, Tribology, Sustainable Machining*

1. INTRODUCTION

Product functionality, good surface finish and aesthetics are some of the selling points of all fabricated products. During machining operations, friction is often generated at the workpiece and tool interface, impacting the final product's surface finish. This friction increases temperature which could eventually result in tool wear, a major cause of material and energy wastage in mechanical machining and eventual reduction of the overall mechanical performance [1]. This challenge necessitates using metal cutting fluid to cushion the frictional effects and regulate the heat generated during the process. According to Astakhov et al. [2], sustaining a constant temperature at the workpiece-tool interface is critical to minimise tool tip welding at the cutting-edge radius and stop machine parts from corrosion. The role of cutting fluids cannot be undermined as *it* improves the efficiency of the machining process, helps to secure a perfect finish and extends the tool life by reducing friction, minimising wear, redistributing heat, and removing contaminants [3].

Over the years, the production of cutting fluids has evolved from mineral to synthetic sources and more recently from biodegradable sources [4]. Mineral oils are obtained from highly processed petroleum products while synthetic oils are made up of artificially synthesized chemical compounds [5]. Compared to conventional mineral oils, synthetic lubricants are notable for exceptional performance relating to their thermal stability and low volatility [6]. Despite this uniqueness in functionality, synthetic lubricants pose major concern such as prohibitive cost, selective applicability, and environmental and health hazards, [7] hence, alternative GMWF from vegetable sources has been proposed as potential substitutes for conventional cutting fluids [8, 9].

GMWFs are formulated from plants and plant seeds stabilized with additives. The base vegetable oils are usually made up of triacylglycerols (91–96%), polar lipids (phospholipids and galactolipids), monoacylglycerols, diacylglycerols, and minor amounts of free fatty acids and poly isoprenoids [5]. Some of the common sources of vegetable oil are cotton seed, groundnut, coconut, sesame, canola, neem seed, soybean etc. Studies have shown that these GMWFs have the potential to provide similar or even better performance than conventional cutting fluids, whilst still maintaining environmental friendliness with minimal or zero health hazards [10 -12]. Notwithstanding the merits of GMWFs, the choice of the appropriate GMWF from the right vegetable source has to be done with optimum formulation ratio as vegetable-based cutting fluids are prone to oxidation instability, high viscosity, and low flash points if not appropriately constituted [13,14]. This can eventually lead to degradation and impede their performance in certain cutting operations.

1.1 Performance of GMWF During Machining

More recently, GMWFs gained pre-eminence for their ability to match their counterparts; mineral oil, and synthetic cutting fluid. Severally, the performance of vegetable-based metalworking fluids has been tested and proven during the mechanical machining operation of different types of material. In machining operations, cutting force, workpiece surface finish, tool wear, and cutting zone temperature are evaluated regarding GMWFs formulation indices [15]. For example, [16, 17] independently developed castor oil-based metal cutting fluid (with different formulations) which was employed during a machining operation on stainless steel alongside conventional cutting fluids to establish their level of effectiveness. This study showed that in addition to the ability of castor oil to match the conventional fluid in terms of good lubricating characteristics and enhanced machining performance, it demonstrated more environmental friendliness. This is because castor oil possesses good antibacterial qualities and provides excellent antimicrobial action against a variety of microorganisms that may be useful in machining applications [18]. Similar to this, Zhang & Poinsettia, Xiaobin et al. [19, 20], created a cutting fluid formulation based on soybean oil with good lubricating, cooling qualities and increased tool life when cutting aluminium alloys.

In another study, rapeseed oil was used to formulate a cutting fluid which is biodegradable, non-toxic, and environmentally beneficial [21]. Also, Yeswanth et al., Ateequr et al. [22, 23], independently developed a cutting fluid from used cooking oil (a supposed bio-waste). This was employed for the machining of titanium alloy and the result revealed that this formulation was environmental compatibility, possesses an excellent cooling quality and show tendencies towards increased tool life.

1.2 Hybrid Cutting Fluids

To attain improved performance, few researchers have concentrated on creating hybrid cutting fluids by combining renewable and non-renewable oils [24]. A combination of soybean oil and synthetic ester created a hybrid cutting fluid that demonstrated good lubricating and cooling qualities and increased tool life when machining titanium alloys [25]. Hybrid cutting fluids produced from a blend of soybean oil, emulsion oil, molybdenum disulfide, and aluminium oxide nanoparticles, [26] were also used to conduct turning trials with difficult-to-cut materials and improved machined surface integrity was reported.

1.3 Formulation Techniques of GMWF

The ratio of base oils, additives, and other ingredients in the blend of GMWF is of great significance to its performance evaluation [27]. [28] reported that functionalizing base vegetable oils like soybean oil, coconut oil and palm oil with additives in the right proportion can make up for some of the deficiencies encountered during mechanical machining with conventional MWFs. However, comparative analysis of the effect formulations (variation in concentration) of the constituting elements of the GMWF especially for the base vegetable oil under consideration; has been grossly underreported. Most research just states the formulation used for developing the cutting fluid without due justification for their choices.

Sravanam et al.[29], developed GMWF that consists of Soybeans oil (75%) Petroleum sulfonate (15%), Ethylene glycol (1%), Oleic acid (3%), Trirthanol amine (3%), Alcohol ethoxylate (2-6%) formulation. However, the researcher never varied the formulation ratio to establish the effect of deviation the control standard. A report by [30] is one of the rare studies that made several comparisons between blends of additives before it eventually settled for a formulation; 6ml Sodium Bicarbonate (Na2CO3) emulsifier plus 10 ml Sodium Oxochlorate additives (NaOCl) added to 20 ml of soybeans oil as the optimum formulation. From the various experimental analyses, Na2CO3 Emulsifier provided the best solubility properties.

In another research, a 1-litre of coconut GMWF was developed with 85% base coconut oil, 10% liquid washing soap and 5% Sulphur as additives. The solution was further mixed with water at a ratio of 1:5 and stirred at room temperature to obtain a 700 ml composition of GMWF [31]. This formulation of coconut oil cutting fluid was adopted as the best constitution due to previous reports of its biodegradability and good environmental impact. [32] also, recorded improved performance of coconut GMWF over mineral oil when the percentage of concentrate in the cutting fluid was maintained at 30% with the distribution of formulation oil in water emulsion. Coconut oil-based concentrate was formulated by mixing coconut oil with Oleic acid and Triethanol Amine in the ratio of 2:2:1 respectively.

It is worth noting that there is a paucity of data regarding the formulation ratio of palm oil-based GMWF. [33] only gave a formulation for sulphuration of the base crude palm oil for a broaching process but did not give details about the percentage constituent of the additives. The quantity of elemental sulphur was varied at 2, 4, 6, 8, and 10% wt, respectively. The desired sulphurized oil had a high sulphur content because it gave a viscosity value which is lower than 86 cSt (centistokes) for the broaching process.

From the literature, it is obvious that MWF is one of the cutting process parameters for subtractive machining processes. The widely used traditional (mineral oil) MWF though relevant in terms of meeting basic minimum machining is far to be desired in modern-day machining operations due to disposal issues, non-biodegradability, depleting mineral reserve health and environmental hazards [34]. Also, the synthetic MWF that is deemed to have superior qualities has its challenges in terms of high cost, and toxicity, and it is easily contaminated by foreign oils [35, 36]. Semi-synthetic MWF, a hybrid cutting fluid, has also been associated with excessive misting, toxicity, relatively poor solubility in hard water, and contamination by foreign oils.

Therefore, this work investigates a GMWF with biodegradable and eco-friendly properties by carrying out chemical modification of three major base oils; Soybean oil, Coconut oil and Palm crude oil. Although GMWFs have some acclaimed drawbacks [7], the primary aim of this work is to improve on the functionality of GMWF by varying the formulation/concentration ratio of the constituting elements to establish a benchmark for optimum formulation ratio, especially for palm oil-based GMWF where reference data are limited in literature.

2. MATERIALS AND METHODOLOGY

2.1 Materials and Equipment

The raw materials for the cutting fluid formulation are; soybeans, coconut and palm fruit. 10 kg of each commercially available sample were purchased from the local market in Auchi, Edo State as indicated in Figure 1. Other additives such as sodium hydroxide used as an-emulsifier, phenol used as a disinfectant, and Triethanolamine (TEA) acting as a corrosion inhibitor and antioxidant were all obtained from the Chemistry Laboratory of Edo State University, Uzairue, Edo State, Nigeria. The material for the machining operation is a 20 mm x 1210 mm AISI 1018 (UNS G10180) steel rod that was cut into 5 pieces for easy clamping and machining to avoid overhang and vibration. The equipment adopted for measurements includes a pH-2601 testing machine, 50ml pycnometer, NDJ-5S Automated rotary viscometer, SRT-6100 Surface Roughness Tester, and Pensky-Marten's apparatus flash point tester was used for the characterization of the formulated oil as shown in Figure 2.

Also, a diamond-shaped cementite carbide inserts cutting tool, and retrofitted lubricant misting were employed for the machining experiment on the Center Lathe machine with specifications as shown in Table 1.

Figure 1: Physical appearance and structure of (a) Soyabean, (b) Coconut fruit and (c) Palm fruit seed

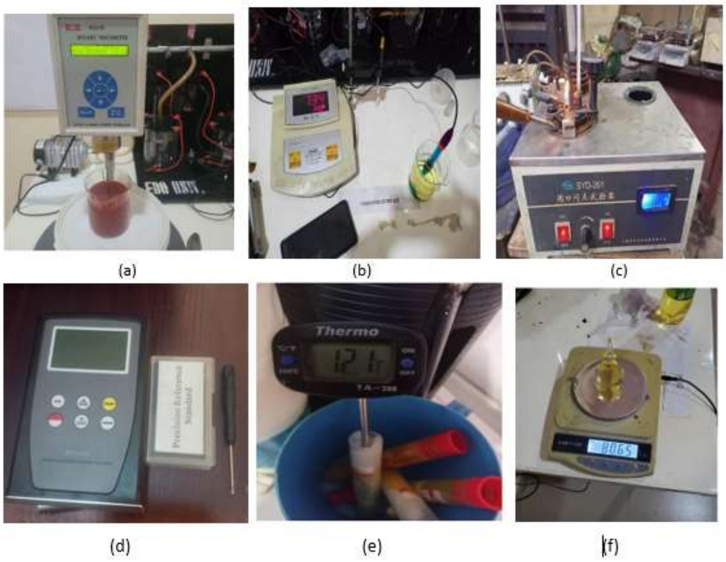


Figure 2: Characterization equipment: (a) Rotary viscometer; (b) Corrosion study kit; (c) Pensky-Martens apparatus; (d) SRT-6100 high accuracy portable surface roughness tester; (e) Pour point thermometer test kit; (f) A Pycnometer and a scale

Table 1: Centre Lathe Machine specification

Centre Lathe Machine	
Model	Triumph 2000
Type	Centre Lathe
Brand	Colchester
Capacity	Ø390 x 760mm Turning
Height of centres	190 mm
Distance between centres	1200 mm
Speed Range	25 ~ 2000rpm
Motor Power	5.5 / 7.5 (kW / hp)
Voltage / Amperage	41510 (V / amp)

2.2 Extraction of Oil

Extraction of base oil is one of the most important steps in the development of GMWF. The summary of the starting material and eventual oil yield as obtained from this investigation is shown in Table 2. The mechanical traditional extraction method using a screw press has been adopted throughout this project as it has the advantage of producing natural and healthy oil though with a relatively lower yield in comparison to the solvent extraction method. The soybean was first prepared by cracking the seeds and mechanically de-hulling them to reduce oil waste. It is further conditioned to about 60 ^{0}C to adjust the moisture content for optimal oil recovery before it was finally fed into a screw press. The seeds are crushed by the rotating screw which eventually uses mechanical pressure to squeeze oil out of the soybeans. The oil is collected in a container while leftover sediments, known as the press cake, are also collected separately for other economic applications as shown in Figures 3 (a), 3(b) and 3 (c).

Extraction of coconut oil started with cracking and de-shelling. The shells were removed and the inner coconut fruits were washed with warm water to adjust the moisture content and temperature for optimal oil extraction. This was immediately followed by grinding with a machine and sieving to separate the milk from the coconut fibre's residue. The milk was further heated until the oil floated on the surface. This was collected for further functionalization as shown in Figure 3 (d)

Threshing and pressing are crucial extraction steps in palm oil extraction. Palm fruits stocked to the bunch were threshed to free the palm fruit seed. It is then washed and boiled for about 45 minutes to soften and condition if for the pressure extraction in a screw press. The extracted oil is indicated in Figure 3 (e).

Table 2: Extraction yield per sample

Base Seed/Fruit	Weight of Base Seed/Fruit (kg)	Weight of Extracted Oil (kg)	Weight of Residue (kg)
Soybeans Grain	10	0.81	8.578
Coconut Fruit	10	0.272	1.63
Palm Fruit	10	1.27	7.86

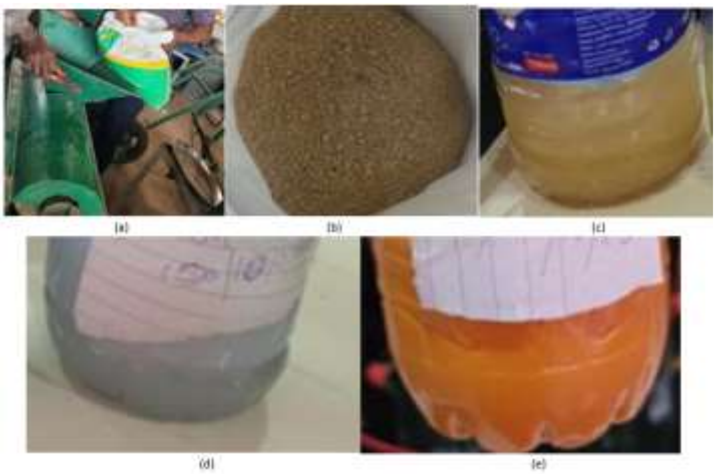


Figure 3: (a) The extraction of seed using a screw press machine; (b) The physical appearance of the pressed cake; (c) Extracted soybeans oil; (d) Extracted coconut oil; (e) Extracted palm oil

2.3 Formulation of GMWF

The acclaimed efficiency of GMWF cannot be achieved solely by the base oil hence, there is a need to blend it with other additives [37]. The major components of the formulation and the intended function of the additives are shown in Table 3 while, Tables 4 and 5 shows the two sets of formulations adopted for this study with percentage proportions of each constituting element.

Table 3: Components of the GMWF formulation

Material	**Function**
Vegetable oil (palm fruit, soybean seed and coconut)	Base oil
Washing soap (sodium hydroxide)	Emulsifier
Tri ethanol amine (TEA)	Corrosion inhibitor & antioxidant agent

Table 4: Cutting fluid formulation 1

Material	**Base oil (%vol)**	**Emulsifier (%vol)**	**Disinfectant (%vol)**	**Pressure agent (% vol)**	**GMWF Designation**
Soybean Oil (S)	80	10	5	5	S1
Palm Fruit (P)	80	10	5	5	P1
Coconut Oil (C)	80	10	5	5	C1

Table 5: Cutting fluid formulation 2

Material	**Base oil (%vol)**	**Emulsifier (%vol)**	**Disinfectant (% vol)**	**Pressure agent (%vol)**	**GMWF Designation**
Soybean Seed	50	40	5	5	S2
Palm Fruit	50	40	5	5	P2
Coconut Fruit	50	40	5	5	C2

2.4 Fluids Characterization

In order to determine the suitability of the extracted oil to match conventional mineral oil, the rheological, physicochemical, and thermophysical characteristics of the extracted oil were investigated. Rheology is the study of the flow/consistency behaviour of fluids in relation to the applied shear stress. The physicochemical behaviour of a fluid defines the physical and chemical structure of the fluid, while thermophysical properties are temperature-dependent behaviours of the fluid. The nature of the internal structure of these drilling fluids is usually very complicated and needs to be well established in order to determine the stability of the oil before application Mello et al., [38]. The following properties of the oil; density, viscosity, pH (acidity and basicity), flash point, and pour point of the oil have been investigated.

3. PERFORMANCE TESTING (MACHINING EXPERIMENT)

3.1 Turning Operation

Machining operation is necessary to evaluate experimentally the performance of the newly developed GMWF. An AISI 1018 mild steel round bar of 20 mm diameter with 127 mm length with properties listed in Table 6 was machined on a Triumph 2000 automatic centre lathe at a speed output of 260 rpm. 25 mm of the AISI 1018 workpiece was clamped in a three-jaw chuck and the remainder was faced and centred on the lathe before the test procedure started as shown in Figure 4. During this turning operation, the GMWF, at room temperature, applied directly on the workpiece tool interface using a retrofitted misting lubrication technique. The above test procedure was repeated for the six samples of cutting fluids S1, S2, C1, C2, P1 and P2 as show in Figure 4 using the same dimension of the workpiece and constant cutting parameters as shown in Table 7. After each turning test, the machine tool was stopped and changed to standardize the tests.

Table 6: Mechanical properties of AISI 1018 mild steel

Properties	**Value**
Hardness, Vickers (Converted from Brinell hardness)	131
Tensile Strength, Ultimate	440 MPa
Tensile Strength, Yield	370 MPa
Modulus of Elasticity (Typical for steel)	205 GPa
Bulk Modulus (Typical for steel)	140 GPa

Table 7: Cutting Parameter for an orthogonal array

Process parameters	**Base oil (%vol)**
Spindle speed (rpm)	260 rpm
Feed rate	2.0 mm/min
Cutting depth	1.0mm

Figure 4: Samples of machined product

3.2 Measurement of roughness of a surface

Upon the completion of the turning operation, the surface roughness of finished workpiece was tested using an SRT-6100 High Accuracy Portable Surface Roughness Tester. This equipment shown in Figure 5 has probe that enables the measurement of roughness of a surface. The tester's stylus tip is equipped with a sensor tip which helps in tracing the surface of the sample. This then electrically detects the stylus' vertical motion. The average estimate of the surface roughness Ra is the arithmetical mean of the deviations of the roughness profile from the central line along the measurement. This was further computed using equation (1) [39].

$$Ra = \frac{1}{L}\int_0^L [y(x)]\,dx \tag{1}$$

Where:
Ra = surface roughness in µm;
L = sampling length;
y = coordinate of the profile curve

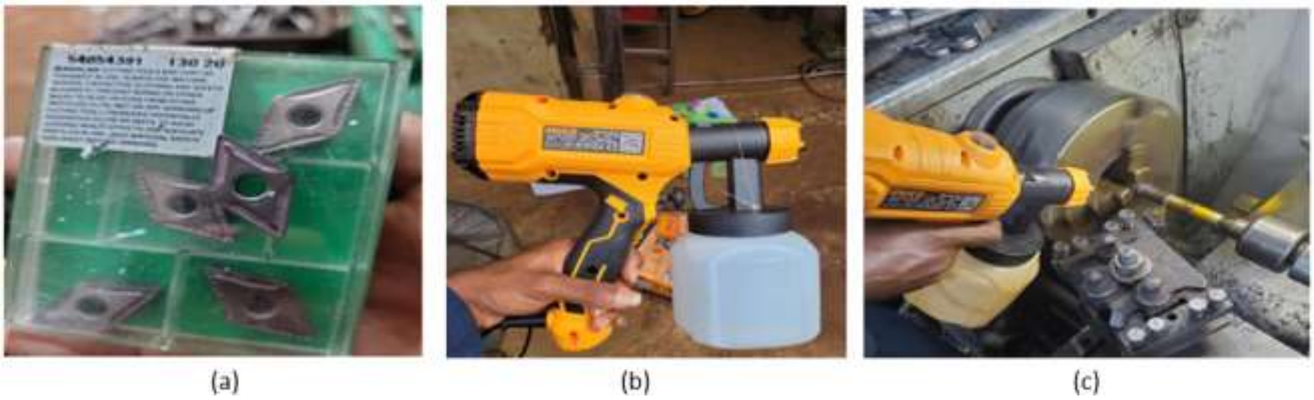

(a) (b) (c)

Figure 5: (a) Diamond-shaped cementite insert tool; (b) Electric spray gun; (c) Turning operation

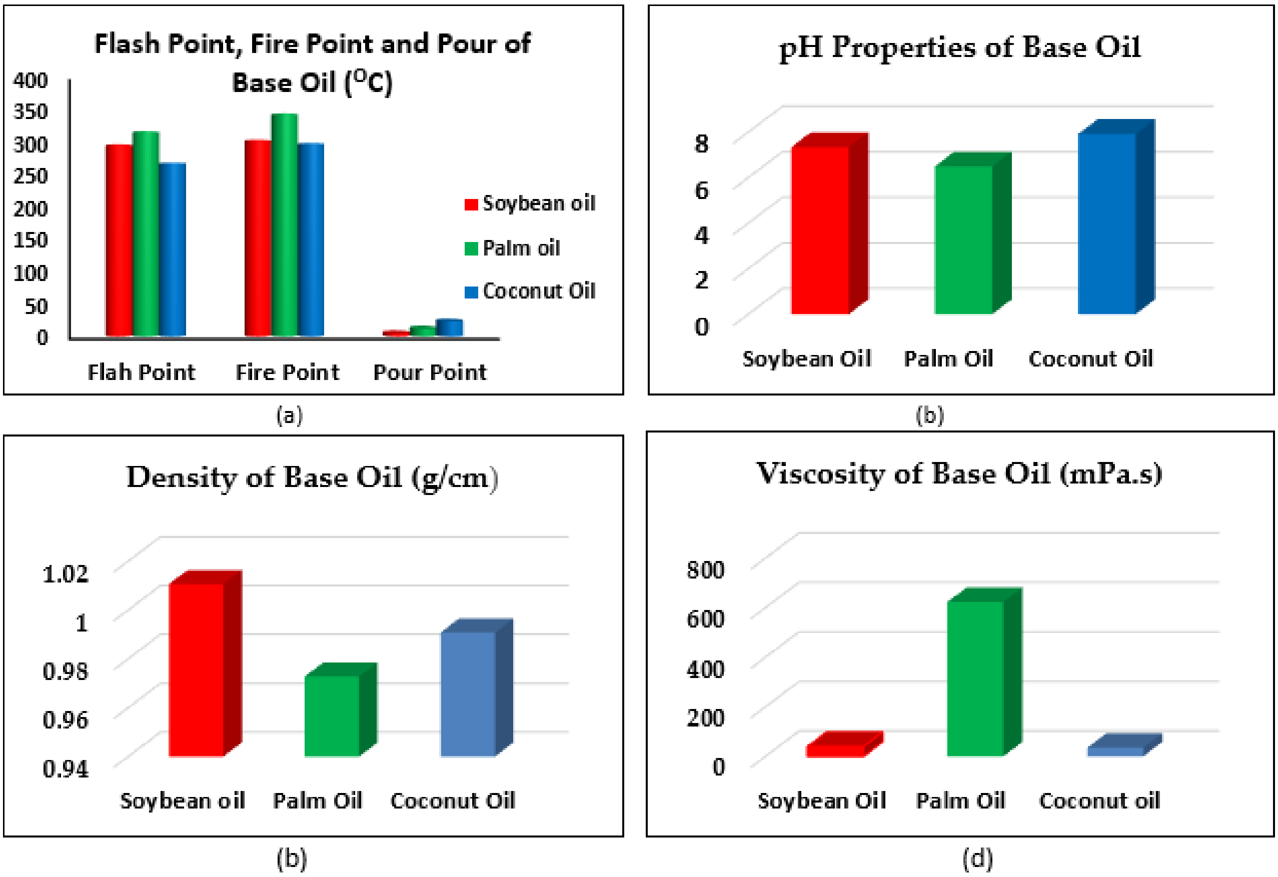
4. RESULTS AND DISCUSSION

4.1 Characterisation of Developed GMWF

4.1.1 Physicochemical analysis of extracted base oils

Figure 6 shows the results of the physicochemical characterization of the base oils, soybean, coconut, and palm oil. It is noteworthy that maintaining a minimum pH of 9.0 is crucial in the majority of cutting fluids. A decrease in pH suggests inadequate concentration or bacterial contamination, which may result in corrosion issues and unpleasant odours. From

Figure 6, it is evident that the pH properties of the extracted base oils are below the standard requirement of between 9-10 [40]. This justifies the need for the introduction of additives in the different formulations of GMWF to stabilize the pH. The density of the three base oils is approximately the same and within the acceptable standard reported in the literature [41]. Palm oil has a very high viscosity compared to other base oils, which is detrimental to the flow property of the oil and needs to be improved by using a viscosity modifier [42]. Additionally, the flash point, fire point, and pour point, though reasonable and comparable to values reported in the literature [29] still require some level of functionalization to be optimal for GMWF."



(a) (b)

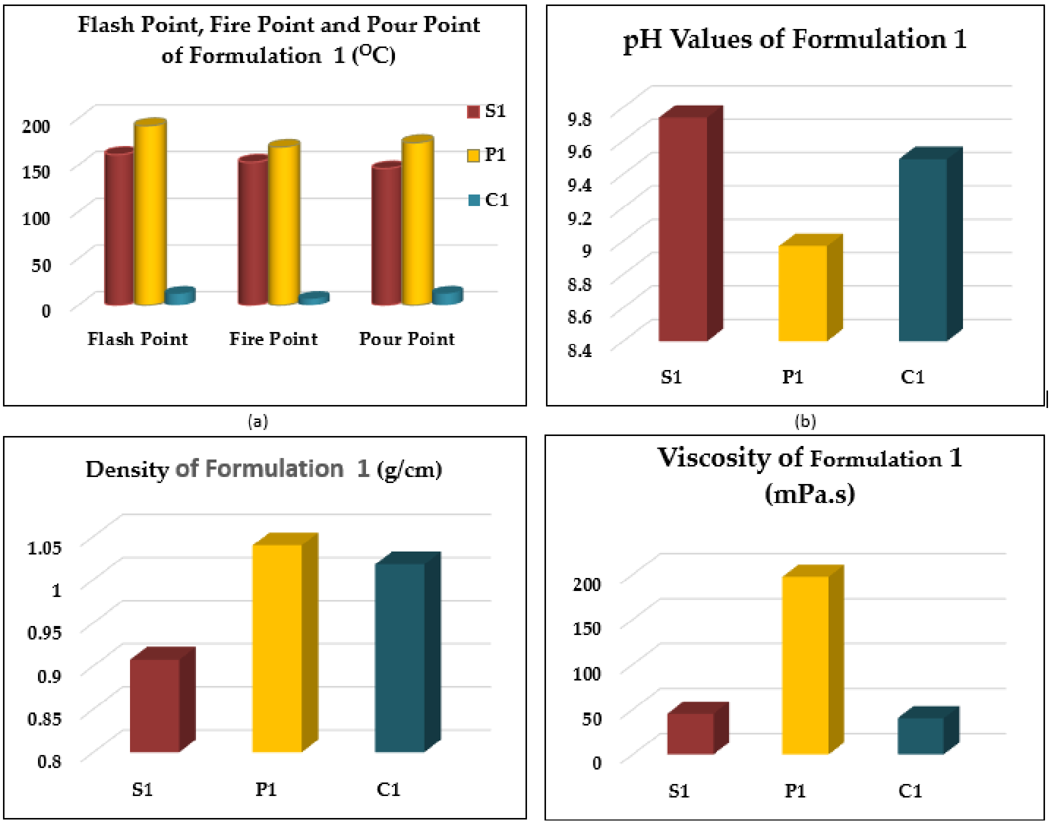
(b) (d)

Figure 6: Physicochemical properties of base oil

4.1.2 Physicochemical analysis of GMWF formulations

Figures 7 show the physiochemical properties of GMWF formulation 1 that is S1, C1 and P1. For all samples, there was a significant improvement in the pH level of the new formulation compared with the base oil. This is an indication of enhanced corrosion and rancidity properties of the developed GMWF. Significantly, sample S1 has the highest fire point showing its ability to withstand a higher temperature range before it becomes flammable. Also, P1 is notable for high viscosity. The viscosity of a lubricant impacts its flow rate and can also be related to its ability to reduce friction and maintain a stable lubricating film at the cutting tool contact zone during machining operations by forcing the tool apart from the workpiece thereby aiding motion [40, 43]. Generally, an optimum value of viscosity is required for successful machining operation as cutting fluid with excessively high viscosity will require a large amount of energy to flow and likewise, low viscous lubricants cannot reduce friction [44, 45]. The viscosity value of 197.5 mPa.s of formulated GMWF PI is within the range of value for palm oil-based formulation as reported by [3]. However, this value does not compare well with that of conventional mineral-based working fluid [46]. Hence, it needs a viscosity modifier for it to feature as GMWF. Other properties such as flashpoint, density and pour point fall almost within the same range of value for the three samples and compare well with the literature [29].

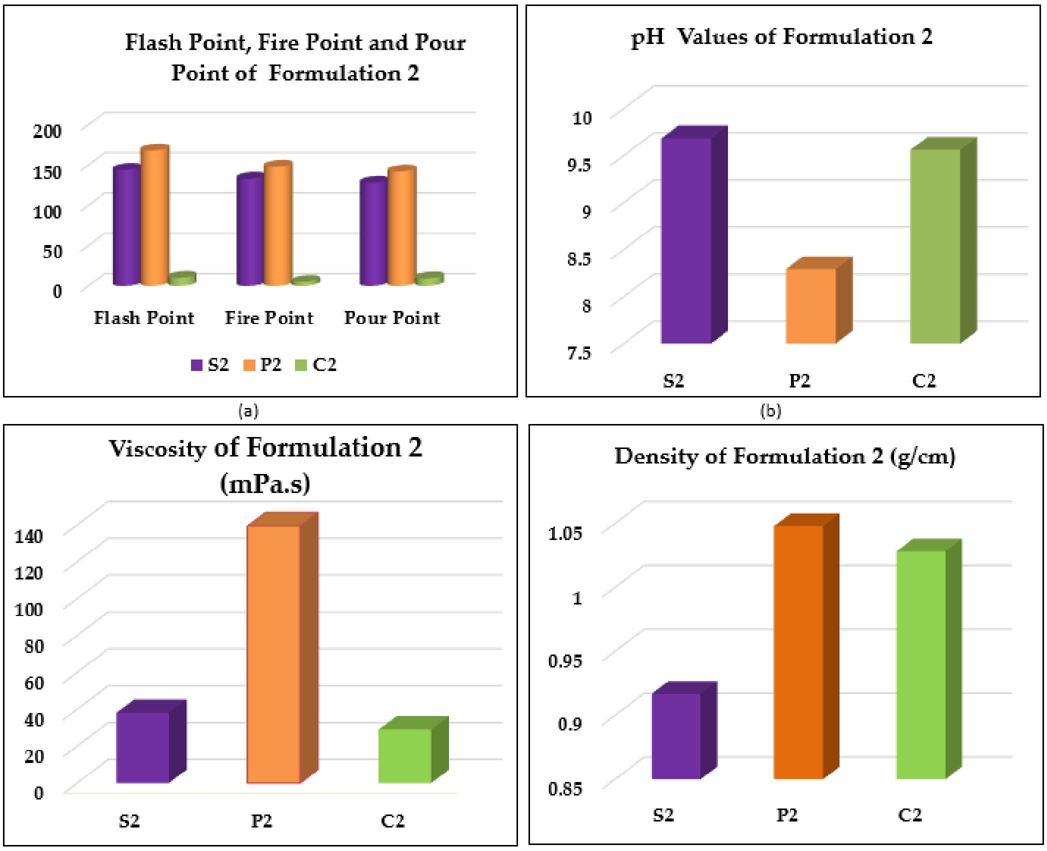
Comparing Formulation 2 in Figure 8 with Formulation 1 in Figure 7, it can be observed that there is a significant drop in all the properties with the exception of the density and pH values of specimen C1 which increased slightly. From this comparison, it could be inferred that Formulation 1 would be a preferred standard for GMWF development.



(a) (b)

(c) (d)

Figure 7: Physicochemical properties of GMWF formulation 1



(a) (b)

(c) (d)

Figure 8: Physicochemical properties of GMWF formulation 2

4.2 Assessment of the Impact of GMWF Formulations on Surface Roughness

4.2.1 Average surface roughness of AISI 1018 with base oils

Figure 9 shows a bar chart of the surface roughness of the three base oils (S, C, and P) during a turning operation on AISI 1018 mild steel at a constant cutting speed of 260 rpm, feed rate of 2.0 mm/min, and cutting depth of 1.0 mm. According to Figure 8, coconut base oil C had the lowest surface roughness value, while palm oil had the highest. A lower surface roughness value indicates good finishing. Therefore, it can be concluded that coconut base oil C, performed best, followed by soybean base oil S. The average surface finish measurements for each base oil and both Formulations 1 and 2 are below the recommended 1.6 µm surface roughness rejection criteria [47, 48].

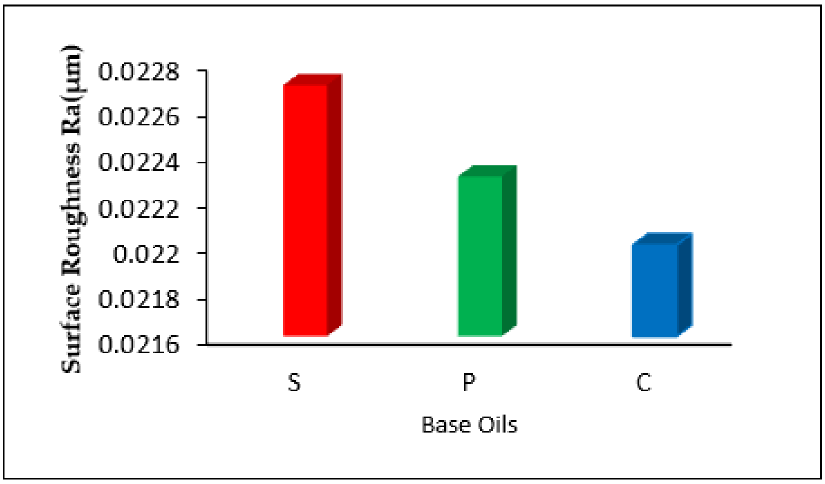


Figure 9: Average surface roughness of AISI 1018 with base oils

4.2.2 Average surface roughness of AISI 1018 with developed S, S1 and S2

A comparison of the average surface roughness of the soybean oil S and the two Formulations S1 and S2 in Figure 10 show the highest value for the base oil and a minimum value for Formulation S1. S1 though high is still lower than its base oil. Analysis of this chart reveals that the incorporation of additives to the base oil had a significant effect on the performance of the GMWF in line with the literature [49]. The Formulation F1 with composition as stated in Table 4 produced a superior surface finish.

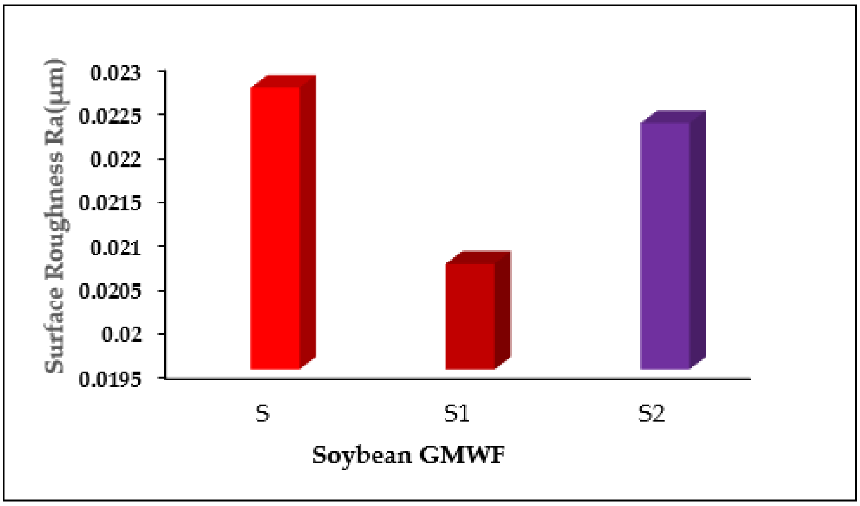


Figure 10: Average surface roughness of AISI 1018 with S, S1 and S2

4.2.3 Average roughness of AISI 1018 with developed C, C1 and C2

Figure 11 presents the machining experiment with coconut base oil C with its formulations C1 and C2. The base oil C, gave a high value of surface roughness followed by the formulation C1 while the formulation C2 produced a better surface finish with a minimum value of surface roughness. The foregoing analysis, explains the material dependence of percentage formulation for GMWF. The particular set additive formulation in terms of composition and constitution that is suitable for a given base raw oil may not be suitable for another hence, the choice of additives need to be carefully determined by a good understanding of the properties of the base oil. The above finding also explains the reason for the paucity of data on standard formulations for MWF as highlighted in the literature gap.

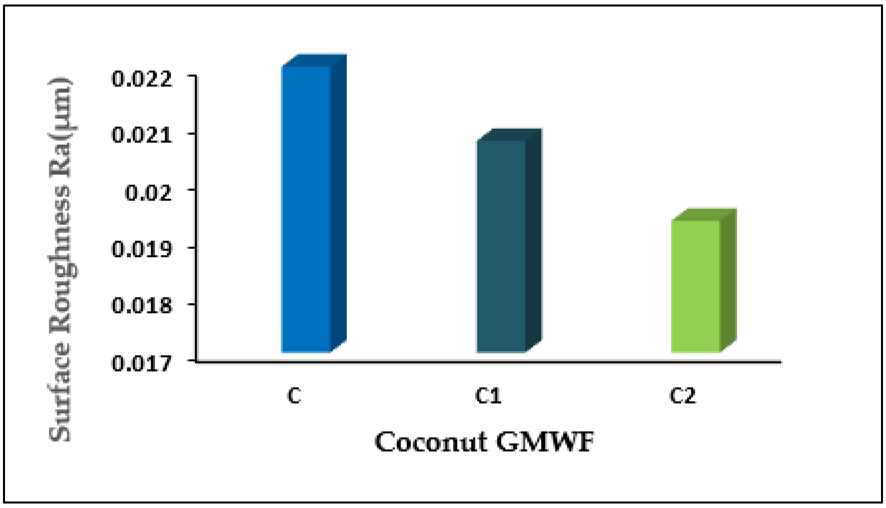


Figure 11: Average surface roughness of AISI 1018 with C, C1 and C2

4.2.4 Average surface roughness of AISI 1018 with developed P, P1 and P2

The results recorded after the machining operation carried out with palm--based GMWF ~~are~~ as shown in Figure 12. The result of this experiment followed a similar trend to that of the soybean formulation. Palm oil GMWF with Formulation P1 produced a better surface finish, while the base palm oil P exhibited a high degree of surface roughness compared to Formulation P2. This result shows the indispensability of additives in the development of GMWF. Additives are indeed needed to enhance the performance of the machining operation, but the choice of formulations is critical to the performance and surface integrity of the finished product.

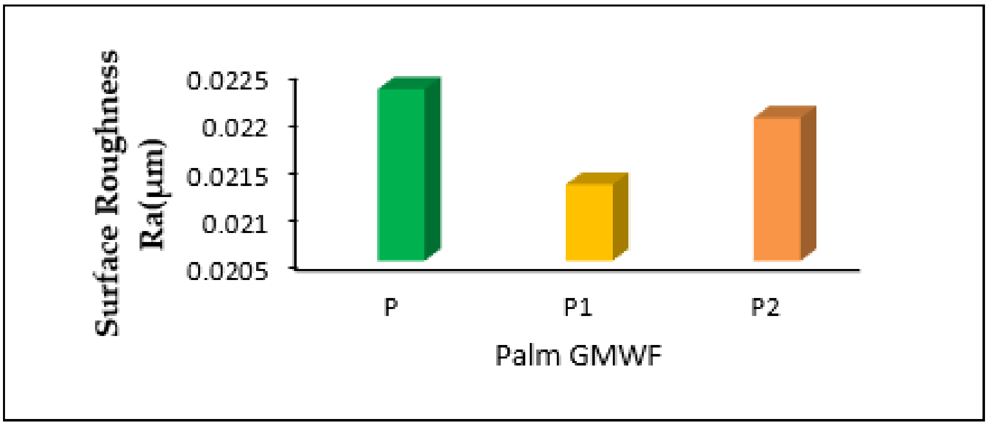


Figure 12: Average surface roughness of AISI 1018 with P, P1 and P2

4.2.5 Comparison of the average surface roughness of AISI 1018 with developed formulations S1, C1, and P1 using mineral oil (Mo).

Figure 13 shows a comparison of the surface roughness of developed GMWF Formulations S1, C1, and P1 with conventional cutting fluid. It is observed that the newly developed formulations S1, C1, and P1, under the same machining conditions of constant feed rate, speed, and feed depth, demonstrated a better surface finish. The average surface roughness of the new GMWF Formulation S1 improved by about 10.77% when compared to conventional cutting fluid.

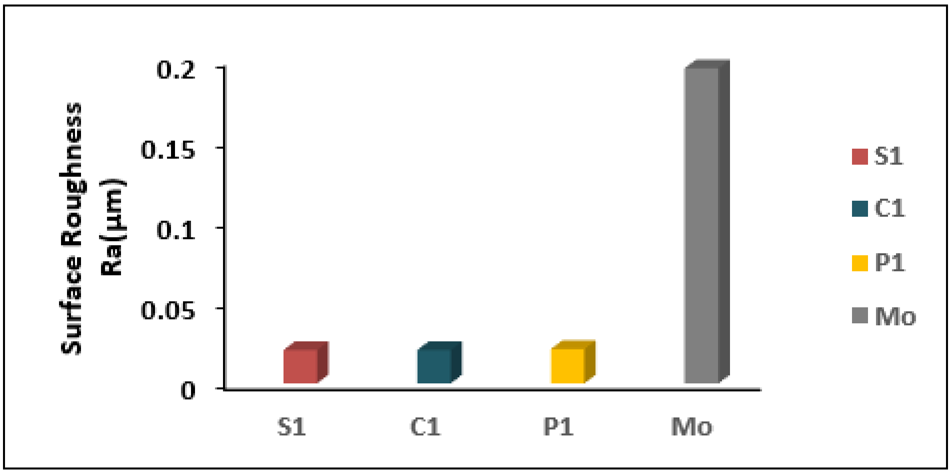


Figure 13: Average surface roughness of AISI 1018 with developed formulations S1, C1 and P1 with mineral oil (Mo)

5. CONCLUSION

This work evaluated the effect of formulation on the performance of GMWF under constant cutting parameters. Developed GMWF cutting fluid formulations were used during the mechanical machining trials to determine their effectiveness and impacts on surface roughness. The deduction from this investigation is hereby outlined:

1. Vegetable oils though possess unique properties that make them attractive substitutes for petroleum-based oils still need some degree of functionalization with additives to be able to feature in the capacity of green metal working fluid.
2. The result of this investigation revealed that the performance of each formulation F1 and F2 is dependent on the base materials used as the formulation F1 and F2 form different base materials had varied impacts. Therefore, the choice of formulation ratios should be determined with reference to the base oil.
3. The experiment also shows that the peculiar limitation of palm oil based GMWF is its excessively high viscosity as observed in Formulations P1 and P2. Extra caution is necessary to determine the viscosity modifier and the right composition that will modulate this property.
4. This study show that the Vegetable based GMWF exhibited a superior performance to the conventional mineral oil hence, functionalized Vegetable oil can conveniently be used as a substitute.

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