IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 09, Issue 3 (March. 2019), ||S (I) || PP 10-19

Evaluation of Apricot Kernel, Avocado and African Pear Seed Oils as Vegetable Based Cutting Fluids in Turning AISI 1020 Steel

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Abstract: A study on the evaluation of Avocado *(Persea Americana L.)* seed (AS), and African pear *(Dacryodes Edulis L.)* seed (APS) and Apricot *(Prunus Armeniaca L.)* kernel (AK), as vegetable based cutting fluids (VBCFs) in the turning of Φ25mm AISI 1020 Steel with high speed steel (HSS) cutting tool was carried out. The turning was performed at varied spindle speeds of 90, 125, 180rpm at constant 0.5mm/rev feed rate and 2mm cutting depth. The cutting fluids were fed to the tribo-interface by gravity. The surface temperature, surface roughness and chip thickness measured in the turning operations using the different VBCFs formulated were compared with those from commercial cutting fluids (CCF). The results showed that increase in speed decreased the surface roughness of AISI 1020 steel; and the least roughness-value was obtained at 180 rpm for AK oil-based fluids. The VBCFs of different formulations all showed good lubricity properties which compared favorably with the CCFs. The VBCFs formulation that showed the best tribological surface cooling characteristics, and lowest roughness and lowest chip thickness formation was Apricot Kernel Oil Cutting fluids (AKOF), even better than the CCFs.

Date of Submission: 21-02-2019 Date of acceptance: 07-03-2019

I. INTRODUCTION

The need for a clean and environmentally friendly cutting fluid (CF) for turning operations has necessitated research into the production of CF from biodegradable materials. Safety of workers and the availabilities of the materials for the production of CF is the more reason why research in this area has become paramount. Some of these researchers have attempted the formulation of CF for drilling and turning operations. Jeevan and Jarayan [1], [2] used the Minimum Quantity Lubrication (MQL) method in the drilling of AISI 304L stainless steel with carbide tool. In the research, the potentials of two vegetable oil based cutting fluids (VBCFs) Neem *(Azadirachta Indica L.)*, and Mahua *(Madhuca Indica L.)*, and commercial mineral oil based cutting fluid (Servocut 945) were tested. Thrust force, surface roughness, temperature and tool wear were used in the performance test, using the Taguchi's orthogonal L27 array. It was evident from the experimental observation and statistical analysis that the Neem and Mahua are alternative to the conventional cutting fluids. Again, the authors used a similar method for turning AA 6061 using Jatropha and Pongamia as straight cutting fluids and mineral oil. It is also valid from experimental observations and statistical analysis that compared to mineral oil; vegetable oil-based cutting fluids (VBCFs) are more effective in reducing cutting forces and increasing surface finish. In addition, Noor El-Din [3] formulated a new metalworking fluid (MWF) with compositions that include emulsifiers, corrosion inhibitor, biocide, and non- edible vegetable oil (castor oil) as the base oil. The castor oil-based metalworking fluid was prepared using nonionic surfactants. The metalworking fluid was optimized by adding to the composition, performance-enhancing additives. Analysis of the performance of the castor oil based MWF was done using Tool chip tribometer and Drill dynamometer. The surface morphology of steel ball and a disc were done using 3D profilometer and SEM. The highly stable castor oil-based MWF in the study was the formulation with Monoethanolamine (MEA) as a corrosion inhibitor.

Mbishida [4] on the performance evaluation of different types of vegetable oils as cutting fluids in machining operations concluded that vegetable oils are good alternatives to the conventional mineral oils as cutting fluids in terms of temperature reduction, tool wear, force and surface roughness. Lawal [5] added that to derive the benefits vegetable-oil based metalworking fluids offers, a study of its effect on emerging alloy materials is crucial. This has necessitated the exploration of African pear *(Dacryodes Edulis L.)* seed oil (APSO), Avocado seed *(Persea Americana L.)* oil (ASO), and Apricot *(Prunus Armeniaca L.)* kernel seed oil (AKO) as cutting fluid in the turning of AISI 1020 mild steel with high speed steel (HSS) cutting tool.

II. MATERIALS AND METHODS

African pear fruit *(Dacryodes Edulis L.)* seeds (APS), Avocado *(Persea Americana L.)* seeds (AS), and Apricot *(Prunus Armeniaca L.)* kernel (AK) (see Figure1) were dried, separately weighed and pulverized in a locally grinding machine. The mixtures gathered were manually cold-pressed to extract the oil, while ISR-16 surface finish tester was used for the measurement of the surface roughness.

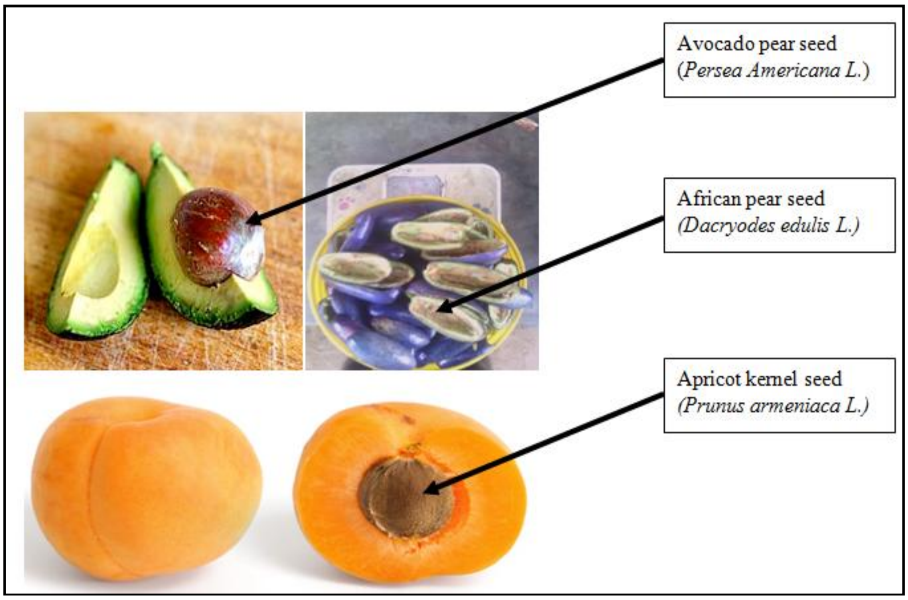

Figure 1: Plate with arrow showing (a) African pear, (b) Avocado pear and (c) Apricot kernel

Three different formulations from African pear seed oil (APSO), Avocado seed oil (ASO), and Apricot kernel oil (AKO) with 80%, 60% and 40% as base-oil respectively were blended with some selected additives as in Table 1 to Table 3. Furthermore, the formulations thus obtained were used as cutting fluid in the turning of AISI 1020 mild steel on a lathe machine *(Lagun, UK)*, with High-speed steel (HSS) cutting tool. The Physicochemical properties of these oils before blending were tested for their acid value, iodine, peroxide value, saponification value, pour point, flash point, relative density, pH, viscosity, refractive index, viscosity index. The cutting parameters used for the evaluation of the cutting fluids responses in the turning operation were cutting speed, cutting depth and cutting time, whereas the cutting fluids performance evaluation criteria include: Temperature, Surface roughness and chip thickness. The turning operations involved turning 25mm diameter cylindrical rod on the lathe to a constant cutting depth of 2mm at a constant federate of 0.5rev/mm.

Table 1: Cutting fluid samples Formulation-1

Material	% Composition (Vol.)			
	African Pear Seed Oil Fluid (APSOF-1)	Avocado Seed Oil fluid (ASOF-1)	Apricot Kernel Oil fluid (AKOF-1)	Commercial Cutting Fluid (CCF-1)
Base oil	80	80	80	80
Washing soap	10	10	10	10
Phenol	5	5	5	5
Sulphur	5	5	5	5

Table 2: Cutting fluid samples formulation-2

Material	% Composition (Vol.)			
	African Pear Seed Oil Fluid (APSOF-2)	Avocado Seed Oil fluid (ASOF-2)	Apricot Kernel Oil fluid (AKOF-2)	Commercial Cutting Fluid (CCF-2)
Base oil	60	60	60	60
Washing soap	10	10	10	10
Tri-ethanol Amine	20	20	20	20
Water	10	10	10	10

Table 3: Cutting fluid samples formulation-3

Material	% Composition (Vol.)			
	African Pear Seed Oil Fluid (APSOF-3)	Avocado Seed Oil fluid (ASOF-3)	Apricot Kernel Oil fluid (AKOF-3)	Commercial Cutting Fluid (CCF-3)
Base oil	40	40	40	40
Oleic Acid	40	40	40	40
Tri ethanol	20	20	20	20
Sulphur	5	5	5	5

III. RESULT

3.1 Seed Oil Yield after cold pressing

Figure 2 shows the seed oil yield, after drying, crushing and cold pressing. Avocado seed *(Persea Americana L.)* (AS) showed the best oil yielding potential; followed by Apricot kernel *(Prunus Armeniaca L.)* (AK) and African pear seed *(Dacryodes Edulis L.)* (APS). These yields were based on equations (1) and (2) for oil yield based on seed weight and yield based on cake weight, respectively. The oils thus extracted were blended into different cutting fluid formulations.

$$Y_1 = \frac{w_1 - w_2}{w_1} * 100\% \quad (1)$$

$$Y_2 = \frac{w_1 - w_2}{w_2} * 100\% \quad (2)$$

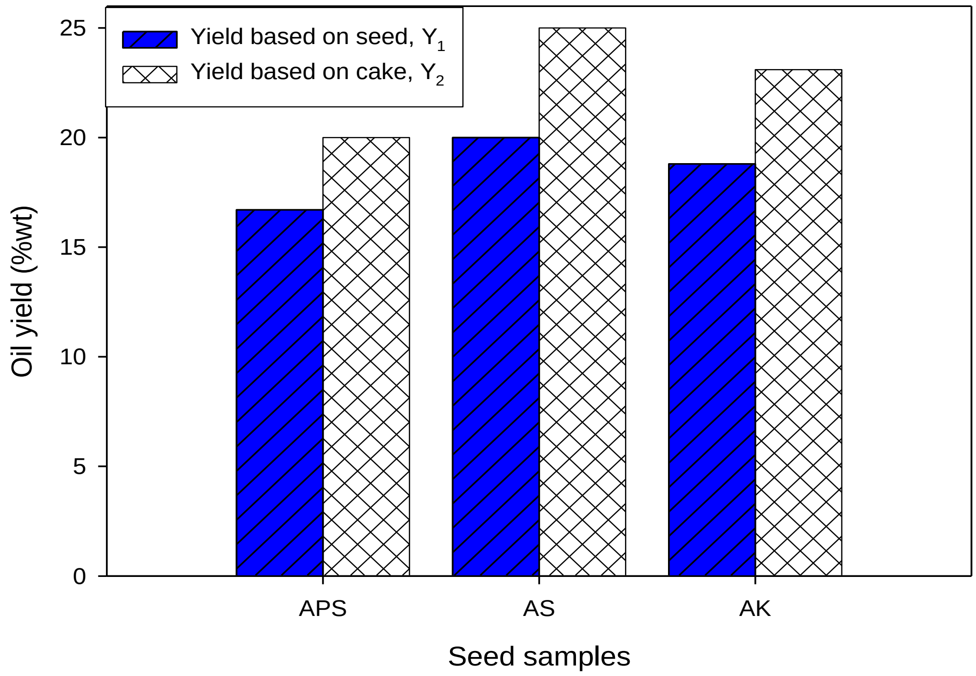

Figure 2: Percentage Oil yield of different seeds based on seed (Y1) and cake (Y2) after cold pressing

3.2 Physicochemical properties of the base-oil

The flash point of oil is the temperature at which the vapour over the liquid will ignite upon exposure to an ignition source. A liquid with flash point less than 60°C is highly flammable. Figure 4 shows the flash point of the CF formulated, and that of the CCF. The flash point for APSO, ASO, AKO, CCF-1, CCF-2 and CCF-3 are 215.900, 228.531, 221.705, 201.810, 220.421 and 230.011°C, respectively. These flash points are greater than the flammability temperature of 60°C thus making the CF suitable for cutting applications and ease of transportation.

Other physiochemical properties of the various seed oils and the commercial cutting fluids Table 4, the acid values of the control samples are higher than that in the developed cutting fluids, except for the avocado oil that has a higher acid value. Other scholars [6], [7], [8], [9]had earlier posited that fatty acid composition of avocado oil depends upon the cultivar, stage of ripening and the geographical growth location and different method used in the processing of the sample. A comparison of the Japanese avocado cultivars and an imported avocado cultivar, revealed no significant differences in the lipid and fatty acid compositions as a result of their stage of ripening and geographical growth location [10]. Cemal [11] showed that wild apricot kernel consist of 93% of unsaturated fatty acids and the main fatty acids are oleic (75%), linoleic (17.5%), palmitic (4.5%) and stearic (2%) acids. The other characteristics of the wild apricot oil are approximate as follows: refractive index (20ºC), 1.469; specific gravity, 0.914 g/cm^3; insoluble matter in the ether, 0.5 %; unsaponifiable matter, 0.7% and iodine value (IV) of 92. All the unblended raw seed oil showed higher IVs in the range of 121.97 – 128.20.

Table 4: Physico-chemical Properties result of the extracted raw Oils samples without blending.

Cutting Fluids	Extracted Raw Vegetable Oil			CCF-1	CCF-2	CCF-3
	African Pear seed oil (APSO)	Avocado seed oil (ASO)	Apricot kernel oil (AKO)			
Acid value (mgKOH/g)	2.707	3.111	2.305	3.970	3.885	2.908
Iodine value (gI_2/100g)	121.973	128.201	121.852	122.674	127.633	123.701
Peroxide value	1.052	0.947	1.0911	1.131	1.091	1.150
Saponification value (mgKOH/g)	175.470	169.985	175.638	175.512	169.707	176.011
pH value	7.30	7.17	7.28	7.29	7.31	7.30
Pour point (^{o}C)	-0.210	-0.110	-0.305	-0.100	-0.201	-0.120
Flash Point (^{o}C)	215.900	228.531	221.705	201.810	220.421	230.011
Specific Density(mg/ml)	0.787	0.832	0.805	0.801	0.803	0.799
Refractive Index	1.975	1.502	2.031	1.317	1.801	1.500
Viscosity @ 40^{o}C(cSt)	4.089	4.409	4.291	4.310	3.807	4.031
Specific Gravity @ (25^{o}C)	0.917	1.071	0.921	0.909	0.920	0.913

3.3 Cooling effect variation with VBCF base-Oil type, concentrationand speed

Figures 3 to Figure 5 present the various responses to the temperature of the base-fluid concentration (formulations) with respect to speed. It is evident from the figures that as the speed increases, the surface temperature of the cutting tool and workpiece (material) interface also increases. As the speed increases there is less quenching (cooling) effect on the workpiece, the reason for the lower interfacial surface temperature at lower speeds for all cutting fluids, irrespective of the base-oil concentration, including the commercial grades CCF-1, CCF-2 and CCF-3. This corroborates the findings of Shaw et al. [12], Cassin and Boothroyd [13] and Kulkami et al [14] who reported that at high cutting speeds, cutting fluid is carried away faster before it reaches the cutting zone to serve as a fluid-film lubricant and the time taken for the fluid to react chemically with the metal surfaces to form a solid-film lubricant is short. It was concluded that lubrication occurs at low speeds by diffusion through the workpiece or that the extreme pressure additives within the fluid react to form a boundary layer of solid-film lubricant, which is in agreement with the work of Noor El-Din [3] and evident as seen in Figures 3-5. Most of the heat generated on the shear plane is carried away in the chip, only very little is conducted into the work-piece which is voluminous in relation to the chip and thus the temperature rise is much lower in the work-piece.

In addition, at high temperature, heat supply from the surface of the workpiece exceeds the amount of heat that can be carried away by the chips and CF. Vapour film forms around the workpiece (material) give rise to relatively slow cooling. In gravity cooling, heat transfer occurs due to the heat of vaporization. Similar phenomena were observed by Agboola [15] on the application of vegetable oil as a quenchant. The duration of the vapour phase and the temperature at which the maximum cooling rate occurs is markedly dependent on the properties of the CF. Although this study, used the gravitational method of cooling, avoiding the vapour phase. Heat transfer rate was that of the heat of vaporization. Therefore, for the 80% base-fluid formulations in Figure 2, all the cutting fluids exhibited comparably similar cooling characteristics from 90rpm to 125rpm speed, but at 180rpm, AKOF-1 followed by ASOF-1 showed the best cooling (quenching) characteristics, even better than the commercial grade CCF-1. This show that the performance of the cutting fluid used depended on the cutting process and the time available for chemical equilibrium to be established on the new metal surface.

A similar trend was observed among the 60% base-fluid formulations in Figure 3, AKOF-2 showed the best quenching characteristics followed by ASOF-2. Vegetable-based cutting fluid APSOF-2 and the commercial cutting fluid CCF-2 showed comparable quenching behaviour. This behaviour is attributed to their high flash point values. For the 40% base-fluid formulations in Figure 4, all the cutting fluids exhibited comparably similar surface temperature at every speed irrespective of the particular vegetable-base-oil source.

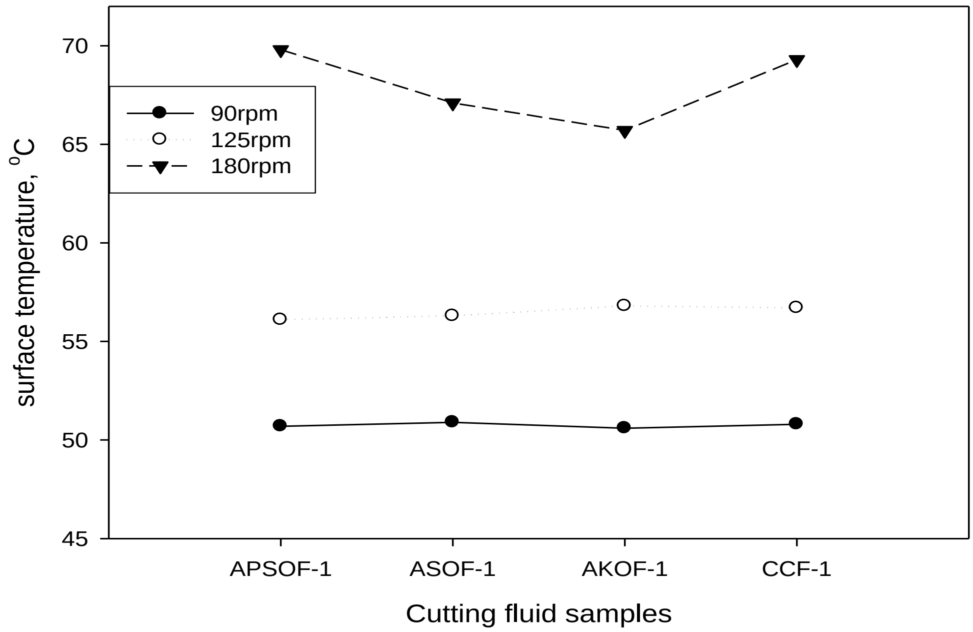

Figure 3: Surface temperature response for cutting fluids with formulation-1

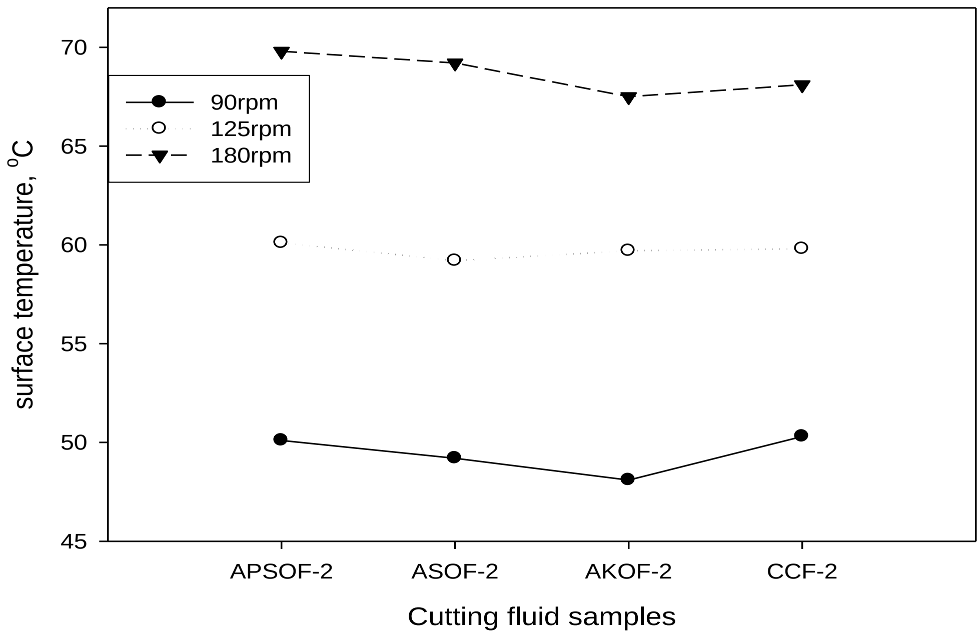

Figure 4: Surface temperature response for cutting fluids with formulation-2

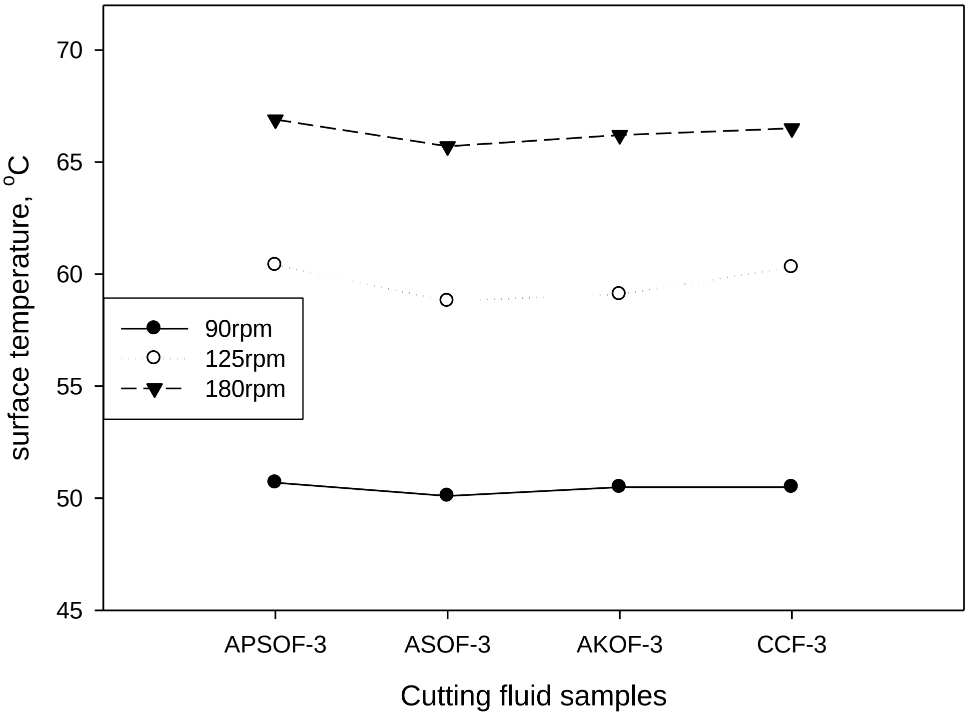

Figure 5: Surface temperature response for cutting fluids with formulation-3

3.4 Chip thickness variation with VBCFs base-Oil type, concentration and speed

Chip formation results from deformation of the workpiece owing to the shear action on the application of force to the cutting tool. The shape and size of the chip obtained from the machining process determine the type and quality of the machining process and ranges from segmental or discontinuous, continuous, continuous with built up edge and non-homogeneous chip. The chip formation is not only dependent upon the work piece material and the shearing force action but on the cutting fluids and grain structure of the materials. From Figures 5 and 6, as the speed increases, the chip thickness at constant federate, varied cutting depth and speeds also increases due to increase in temperature on the workpiece (material) and the tool interface, for all the VBCFs and commercial cutting fluids, irrespective of the composition (formulation). This is in agreement with the work of Kulkarn [14], on some vegetable-based oil; the chips produced under both dry and wet condition were continuous at higher speed rates. While at lower speed, the chips were continuous with helical shape. In wet condition, the chip thickness decreased owning to temperature reduction on the surface of the workpiece (material) and tool interface. Thus is an indication that cutting tool fluid (CTF) and cutting conditions are the significant factor effect on chip formation and chip thickness. The latter is evident in Figure 6; chip thickness is dependent on the properties and composition of the cutting fluids. Variation of chip thickness with respect to speed in the AKOF-1 and AKOF-3 formulation in Figure 6 and Figure 7 is a clear evident of this phenomenon. Further, Figure 7 at a rotational speed of 125rpm, the chip thickness of CCF-3, ASOF-3 and the APSOF-3 increases above the chip thickness formation at 180rpm, while that of the AKOF-3 maintain the normal chip thickness formation with those of Figure 6 and Figure 7. This can be attributed to the fact that the Apricot kernel Oil cutting fluid (AKOF) is a suitable cutting fluid and reduces the temperature of the tool tip and work piece as the speed increases.Cemal et al [11] showed that wild apricot kernel consist of 93% of unsaturated fatty acids and the main fatty acids are oleic (75%), linoleic (17.5%), palmitic (4.5%) and stearic (2%) acids, which give AKOF, better cooling and lubricity properties.

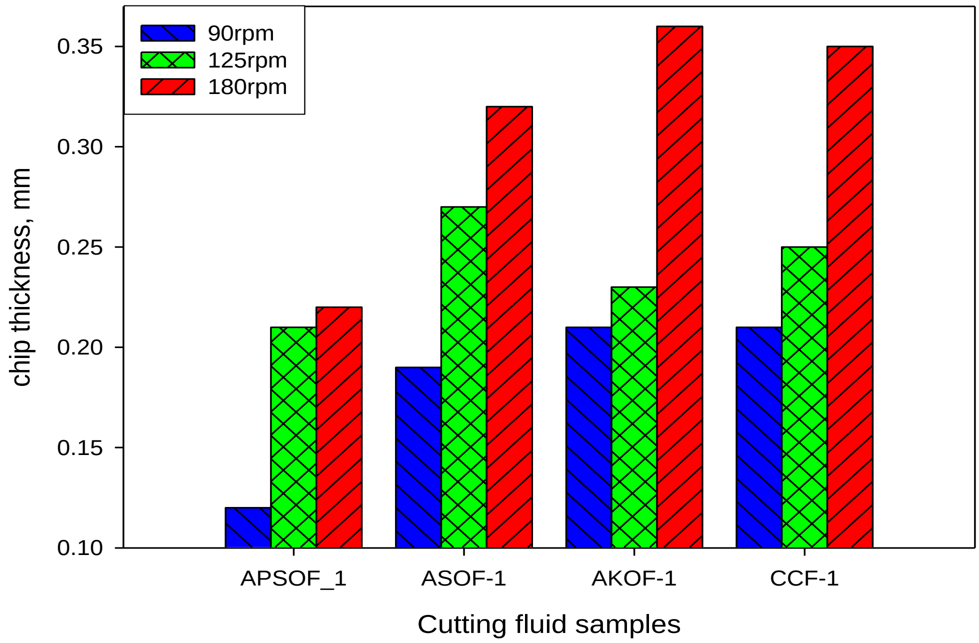

Figure 6: Chip thickness response for cutting fluids with formulation-1

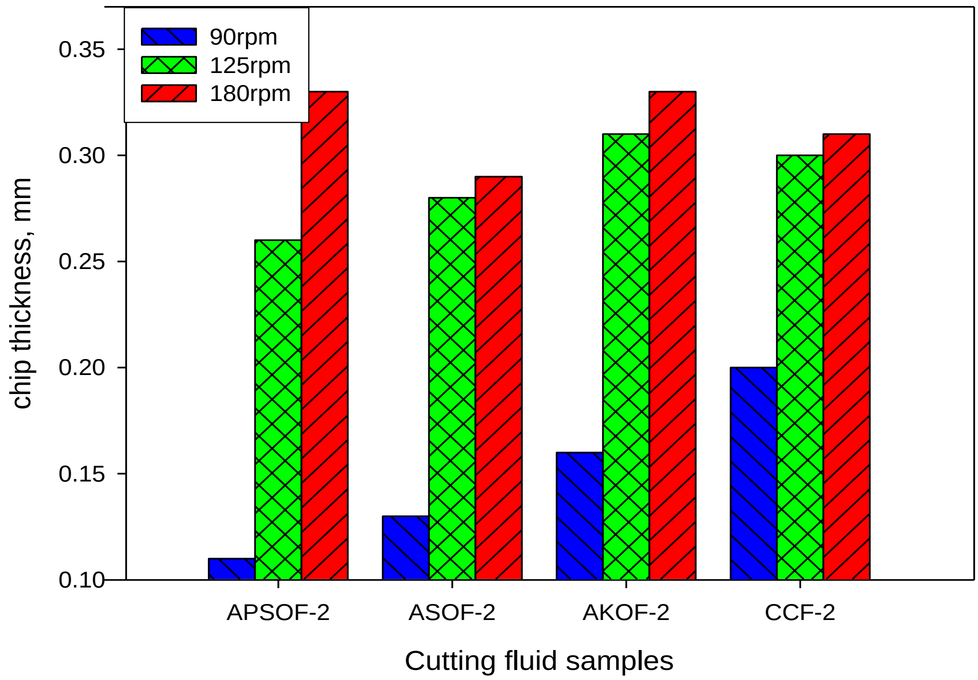

Figure 7: Chip thickness response for cutting fluids with formulation-2

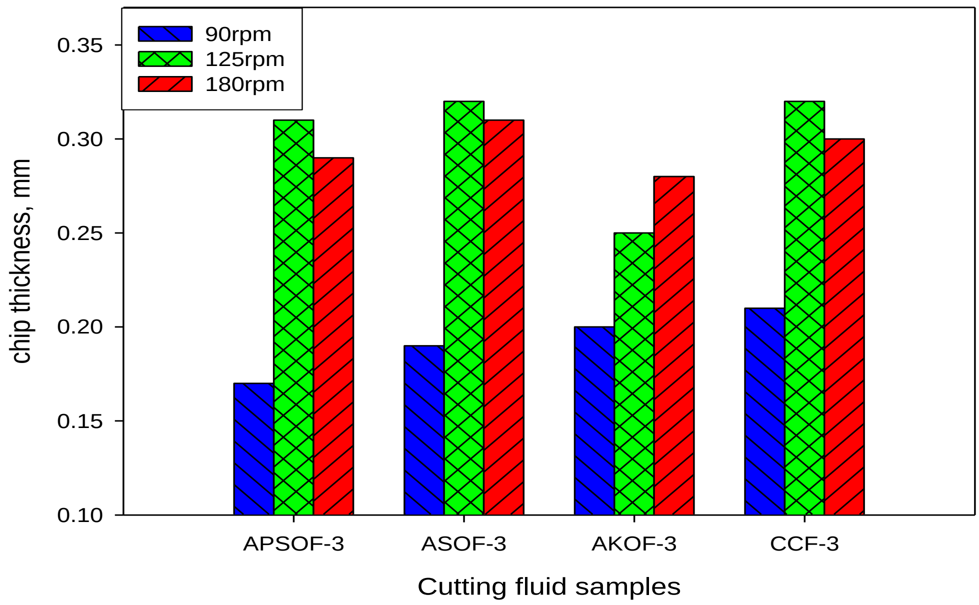

Figure 8: Chip thickness response for cutting fluids with formulation-3

3.5 Surface roughness (finish) variation with VBCF base-Oil, concentration and speed

Factors that may affect the surface roughness in turning operation are the minimum chip thickness, vibrations or damages on the cutting tool edge [Paul et al,][16]. However, the cutting fluids also have a significant effect on the surface roughness of the workpiece. The mean Ra values from the different formulation are presents in Figures 9-11, from the figures, as the speed was decreased the surface roughness in all the formulations increases. While an increase in the spindle speed decreased the surface roughness values. In addition, based on the concentration of the CF in relation to the surface roughness, formulation-3 (Figure 11) with 40% concentration of VBCF is the best formulation compared to the 80% concentration (Figure 9) and 60% concentration (Figure 10) at the spindle speed of 180 rpm, 125 rpm and 90 rpm respectively. It is therefore evident that high spindle speeds reduced forces, vibration and the balance in the right recipe of the additives and the VBCFs enhance surface finish of workpiece in turning operation. In comparison with the individual CF from the different formulations, formulation-3 (Figure 11), AKOF-3 cutting fluid has the best surface roughness at a spindle speed of 180 rpm. This therefore confirms the effectiveness of fatty acid concentration in the AKOF, which aid in the cooling and improvement of the lubricity properties of CF.

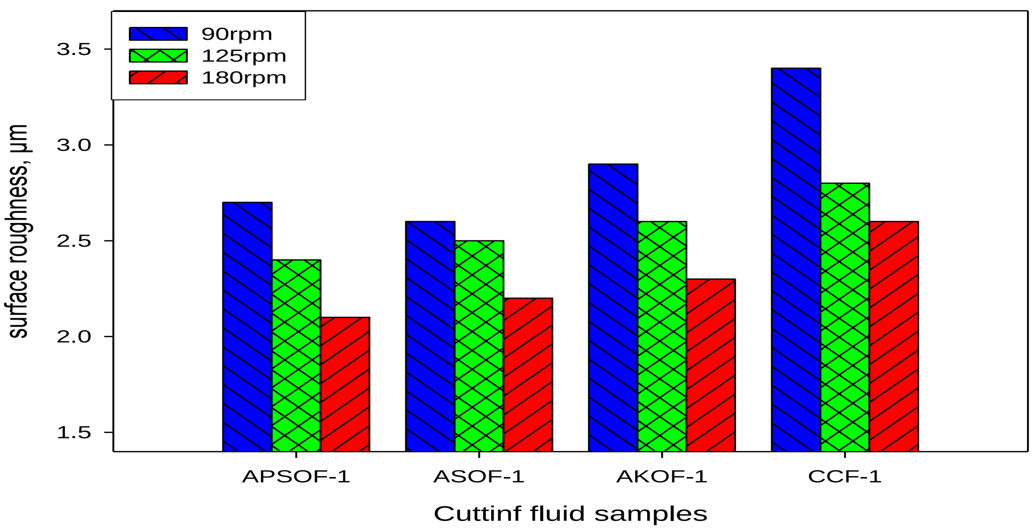

Figure 9: Surface finish response for cutting fluids with formulation-1

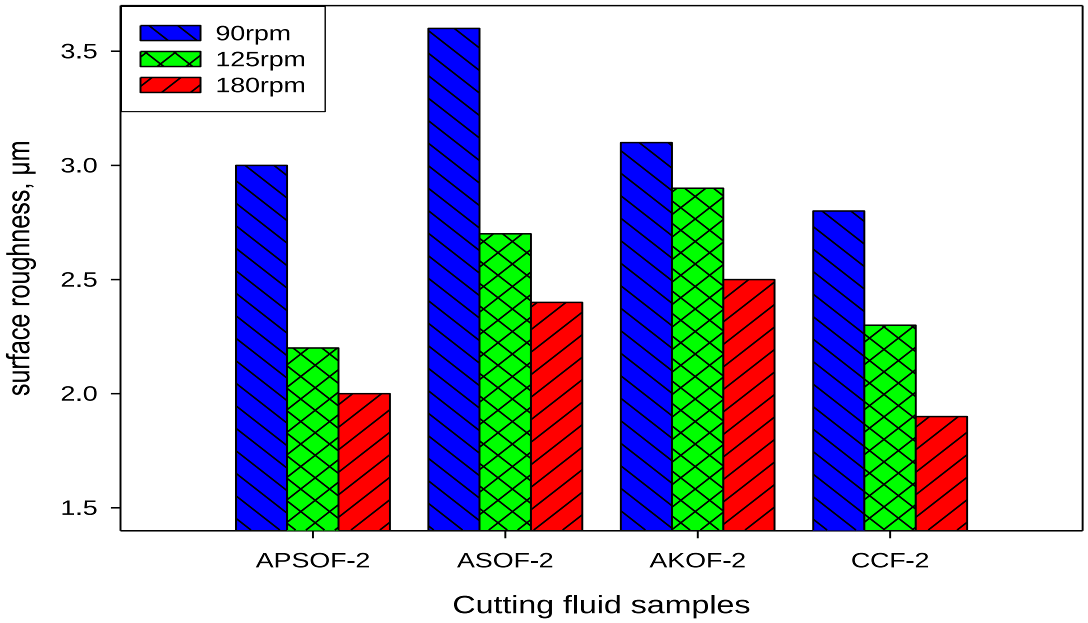

Figure 10: Surface finish response for cutting fluids with formulation-2

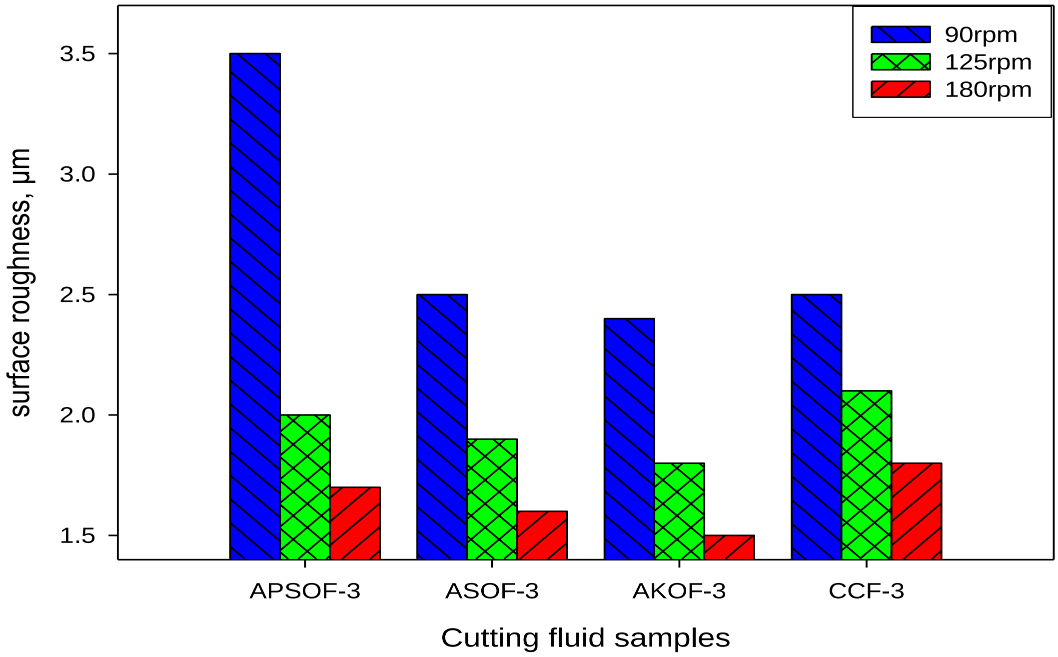

Figure 11: Surface roughness response for cutting fluids with formulation-3

IV. CONCLUSION

Evaluations of the effect of African pear seed (APS), Avocado seed (AS), and Apricot kernel (AK) oils as cutting fluid in the turning of AISI 1020 mild steel with High Speed Steel (HSS) cutting tool based on surface Temperature, Surface roughness and Chip thickness were performed and the obtained results were compared with those of commercial cutting fluids. The following conclusions were drawn from the analysis of the results:

a) In all the formulations, Apricot Kernel Oil Cutting fluids (AKOF) showed the best tribo-pairs surface cooling characteristics and lower surface roughness at high speed and lower chip thickness formation, even better than the commercial cutting fluids and other vegetable-based cutting fluids (VBCFs).

b) An increase in the spindle speed decreased the surface roughness value of the workpiece. The least surface roughness was achieved at spindle speed of 180 rpm.

c) Finally, in comparison with the three commercial cutting fluids formulations African pear seed (APS) oil, Avocado seed (AS) oil, and Apricot kernel (AK) oil showed good lubricity properties derived from the surface roughness measurement in all the formulations.

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Eziwhuo S.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 Steel." IOSR Journal of Engineering (IOSRJEN), vol. 09, no. 03, 2019, pp. 10-19.