Verification of Some Vegetable Oils as Cutting Fluid for Aluminium

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ABSTRACT: Vegetable oils (palm oil, groundnut oil, shear butter oil and cotton seed oil) have been used as lubricants in the turning operation of aluminum under varying spindle speeds, feed rates and depths of cut and the results compared with kerosene (due to the gummy nature of aluminium metal). The parameters investigated are the chip thickness ratio, surface finish and surface temperature. Their performances when compared with the conventional soluble oil have shown that they can perform the same functions as imported ones in the machining of aluminum. They reduced chip thickness ratio, improved surface finish and exhibited good cooling behaviour at the work piece-tool interface. This performance is due to their high viscosities and the presence of surface active agents such as *stearic* acid and halogens, such as chlorine which help to reduce surface energy of a liquid and increase its wetting ability or oiliness.

KEYWORDS: vegetable oil, chip compression, surface roughness, temperature, surface active agents

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I. Introduction

Several methods have been used to source for lubricants for metal cutting (Obi and Oyinlola, 1996; Cholakov and Rowe, 1992). These methods include measurement of tool wear rate, measurement of heat removal rate, determination of chip compression and coefficient of friction. Machining operations are one of the most effective methods of evaluating lubricants because the cutting fluid can alter the forces between the tool and the work piece, tool-chip interface temperature, shear angle, power consumption, heat generation, wear, tool life, chip form and surface roughness (Obi, 1997). Turning processes involve high local temperatures and friction at the chip-tool interface hence most practical machining operations use cutting fluids developed to ameliorate these effects.

The cutting fluid reaches the chip-tool interface by processes such as diffusing through the distorted structure of the metal or by capillary action. In the cutting of metals, work is done in the plastic deformation of the layer being cut at the primary shear plane, in overcoming friction in tool-chip interface called the secondary shear plane and the layers adjoining the machined surface and the tool flank or the tertiary shear plane (Smith, 1993). Part of the heat generated passes into the tool and reduces its hardness and makes it less wear resistant. The credibility of lubricants can be determined from measuring the chip thickness ratio defined as the ratio of chip thickness size to that of the chip. In an earlier investigation (Childs, 2000), it was observed that chip thickness is strongly influenced by lubrication. In an air atmosphere the chip formed was thick but adding a lubricant caused the chip to become thinner and curled. That is, adding lubricant caused the friction between chip and tool to reduce.

Reduction in chip thickness ratio is usually associated with reduction in cutting force, cutting temperature and power consumption. Increasing the speed, the feed or the true rake angle of the tool usually reduces the chip thickness ratio (Childs, 2000). Good surface finish is an unquestionable outcome of every machined part with a few exceptions and it is influenced by the type of cutting fluid used. Most of the lubricant development processes in the literature are cantered on single effect outcomes such as frictional effects, heat generation effect, roughness values and so on. Few investigators had bothered about two or more combined outcome while designing a particular fluid for metal cutting. The present work looks at the effects of the vegetable oils under development on chip compression, roughness values and temperature of machined surfaces of aluminium while varying the speed, the depth of cut and feed. The vegetable oils chosen are palm oil, groundnut oil, sheabutter and cotton seed oil.

II. Materials and Methods

The materials used for this study include:

1. Lathe machine – Model: Metalx WARSZAWA, Serial No. TUE40-9800, Manufactured in 1972, Polish.

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2. Cutting tool – High speed steel with 10° rake angle, 9° clearance angle, 1.5mm nose radius with 10mm tool overhang.
3. Infrared thermometer of type RayTEMP 38, Code 814-038, manufactured by Electronic Temperature Instruments Ltd, UK.
4. Micro-meter screw gauge
5. Aluminium work pieces

The effect of cotton seed oil, palm oil, ground nut oil and shear butter oil on the chip thickness ratio, surface finish and surface temperature of the workpiece at varying spindle speeds, depths of cut and feed rates on the turning of aluminium were carried out on a centre lathe machine using a high speed steel (H.S.S) cutting tool. The turning operations were also carried out using kerosene as control because of the gummy nature of aluminium during machining.

The experiments were carried out with the following specific procedures using the cotton seed oil as the cutting fluid.

1. Turning operations of aluminium at varying spindle speeds (90, 125, 180, 250, 355 rev/min) and at constant feed rate of 0.5mm/rev and constant depth of cut of 2mm.
2. Turning operations of aluminium at varying feed rates (0.1, 0.2, 0.3, 0.4, 0.5 mm/rev) and at constant spindle speed 180 rev/min and constant depth of cut of 2mm.
3. Turning operations of aluminium at varying depths of cut (1, 1.5, 2, 2.5, and 3 mm) and at constant feed rate of 0.5mm/rev and constant spindle speed of 180 rev/min.
4. Procedures 1, 2 and 3 were repeated using palm oil, ground nut oil and shear butter oil as the cutting fluid.
5. Procedures 1, 2 and 3 were also repeated using kerosene as reference cutting fluid for aluminium (due to the gummy nature of aluminium).

During each turning operation the surface temperature was measured using the infra-red thermometer by aiming the thermometer at the target at a distance of 100 mm and firing the trigger. The temperature value is read off a digital display. The surface roughness was obtained using the surface roughness templates. The chip thickness was measured using the micrometer screw gauge and the corresponding chip thickness ratio was calculated using eqn. (1).

$$chip\ thickness\ ratio = \frac{Chip\ thickness\ t_c}{depth\ of cut\ d_c} \quad (1)$$

III. RESULTS AND DISCUSSION

The values given in Tables 1 - 3 show the effects of varying spindle speed at constant feed, varying the feed at constant depth of cut and varying the depth of cut at constant feed. In each case the following measurements were made: chip thickness, chip thickness ratio, surface roughness and surface temperature using kerosene (standard) and the vegetable oils under evaluation (viz: palm oil, ground nut oil, shear butter oil and cotton seed oil) as the cutting fluid during the turning operation of aluminium.

Table 1: Effect of varying spindle speed on machining of Aluminium at constat feed rate of 0.5 mm/rev and depth of cut of 2mm

Lubricant	Speed (rpm)	CT (mm)	CTR	SR (μm)	ST (°c)
kerosene	90	0.215	9.30	1.60	35.0
	125	0.240	8.33	1.60	31.0
	180	0.225	8.886	1.60	34.0
	250	0.210	9.52	1.60	35,0
	355	0.535	3.74	1.60	34.0
Palm oil	90	0.220	9.09	3.20	38.3
	125	0.200	10.00	2.40	45.0
	180	0.183	10.92	1.60	33.6
	250	0.180	11.11	2.25	49.3
	355	0.195	10.26	1.20	53.9
Groundnut oil	90	0.185	10.81	2.40	40.9
	125	0.175	11.43	3.20	40.4
	180	0.220	9.09	2.75	40.4
	250	0.160	12.50	2.40	40.8
	355	0.240	8.33	2.20	47.5
Shear butter	90	0.175	11.43	2.40	32.9
	125	0.250	8.00	2.20	35.1
	180	0.137	14.60	2.20	41.9
	250	0.155	12.90	2.00	40.1
	355	0.170	11.77	1.60	33.9
Cotton seed oil	90	0.400	5.00	3.20	35.3
	125	0.260	7.69	2.40	36.7
	180	0.240	8.33	2.20	39.2
	250	0.115	17.39	2.20	43.5
	355	0.150	13.33	2.00	42.6

Table 2: Effect of varying feed rate on machining of Aluminium at co nstat speed of 180 rev/min and depth of cut of 2mm

Lubricant	Feed (mm/rev)	CT (mm)	CTR	SR (μm)	ST (°c)
kerosene	0.1	0.215	9.30	1.60	34.0
	0.2	0.150	13.33	1.60	33.0
	0.3	0.080	25.00	2.40	31.0
	0.4	0.210	9.52	3.00	30,0
	0.5	0.535	3.74	3.20	34.0
Palm oil	0.1	0.395	5.06	1.25	32.2
	0.2	0.285	7.02	1.60	36.8
	0.3	0.210	9.52	1.80	44.4
	0.4	0.180	11.11	2.00	42.4
	0.5	0.183	10.93	2.40	41.8
Groundnut oil	0.1	0.460	4.35	2.00	39.9
	0.2	0.335	5.97	2.20	35.8
	0.3	0.210	9.52	2.40	43.6
	0.4	0.180	11.11	2.80	37.6
	0.5	0.185	10.81	3.20	35.8
Shear butter	0.1	0.050	4.00	2.00	38.4
	0.2	0.240	4.35	2.22	39.1
	0.3	0.215	9.30	2.55	43.9
	0.4	0.155	12.90	2.55	44.8
	0.5	0.155	12.90	2.80	46.8
Cotton seed oil	0.1	0.400	5.00	2.00	39.1
	0.2	0.260	7.69	2.25	47.1
	0.3	0.240	8.33	2.40	41.8
	0.4	0.115	17.39	2.55	42.2
	0.5	0.150	13.33	2.80	39.2

Table 3: Effect of varying depth of cut on machining of Aluminium at constat feed rate of 0.5 mm/rev and speed of 180 rev/min

Lubricant	DC (mm)	CT (mm)	CTR	SR (μm)	ST (°c)
Kerosene	3.0	1.37	2.19	1.60	30.0
	2.5	1.30	1.92	2.40	32.0
	2.0	1.35	1.42	3.20	34.0
	1.5	1.39	1.08	4.40	35.8
	1.0	1.17	0.85	4.84	38.5
Palm oil	3.0	1.12	2.68	2.00	49.7
	2.5	1.06	2.36	2.40	45.6
	2.0	1.17	1.71	3.20	44.4
	1.5	0.99	1.61	3.25	36.8
	1.0	0.90	1.11	3.60	32.8
Groundnut oil	3.0	1.24	2.42	2.75	39.9
	2.5	1.31	1.91	3.20	35.8
	2.0	1.35	1.48	3.60	33.6
	1.5	1.12	1.34	4.00	33.4
	1.0	0.92	1.09	4.80	31.8
Shear butter	3.0	1.21	2.48	2.55	49.1
	2.5	1.26	1.98	3.30	46.8
	2.0	1.29	1.55	3.55	43.9
	1.5	1.09	1.38	4.00	41.2
	1.0	1.10	0.91	4.60	38.5
Cotton seed oil	3.0	1.08	2.78	2.75	49.1
	2.5	1.26	2.36	3.60	47.1
	2.0	1.08	1.08	3.80	41.8
	1.5	0.99	1.52	4.20	42.2
	1.0	0.85	1.18	4.80	39.2

CT=chip thickness; CTR=chip thickness ratio; SR=surface roughness; ST=surface temperature; DC=depth cut

Figures 1, 2 and 3 show how these operations respectively affect the chip compression; figures 4, 5 and 6 the surface roughness and 7, 8 and 9 the surface temperatures of the material.

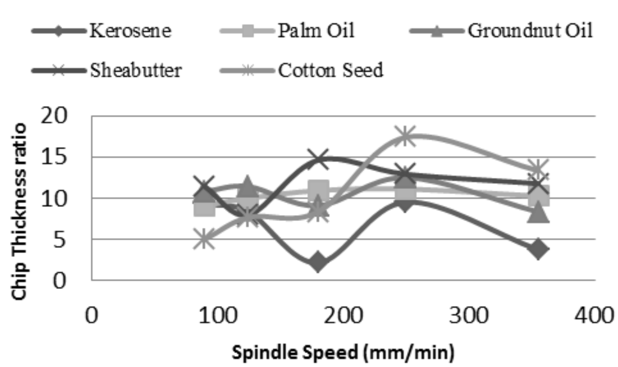

Figure 1: Effect of spindle speed on the chip thickness ratio for aluminium at constant feed rate of 0.5rev/mm and depth of cut of 2mm

Figure 1 shows that there is a slight decrease of chip compression with speed, followed by a slight rise and a decrease again. Earlier research (Leyesenter, 1966) has shown that with an increase in cutting speed, chip thickness is first reduced reaching a minimum, then increases reaching a maximum after which it drops again and that at high speeds varies slightly. This variation in chip compression is due to the changing values of the actual cutting angle, formation of built-up edge and variation of fiction. The main variables affecting chip contraction are the cutting angle, the cutting speed, rate of feed, cutting fluid and the metal being machined and its mechanical properties. Rosenberg and Yeremin's (1973) investigation showed that at low cutting speeds there is no built up edge because a discontinuous chip is produced and cutting temperature is low. As the cutting speed is increased the chip changes to inhomogeneous and continuous types, flow of plastically deformed layers is observed and the temperature is such that the formed stagnant zone becomes hardened, arrested and welded onto the tool face. At further increase in the cutting speed, the temperature rises and the stagnant zone being softened is reduced in extent until it disappears. The value of the cutting speed at which the built up edge disappears depends on the cutting angle. Also when lubricants are used, chips are thinner, that is, a better lubricant should give a higher reduction in chip compression with feed and speed which is an indication of reduction of cutting force, power consumed and temperature and that these depend on the cutting fluid used (Obi, 2000). All the lubricants investigated exhibited the above trend except palm oil where chip compression increased gradually to a maximum and commenced a gradual decrease. This could be because the speed range of investigation is not large enough for palm oil.

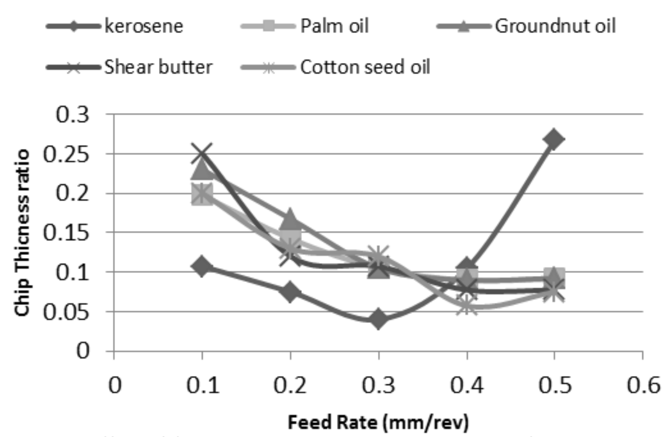

Figure 2: Effect of feed rate on the chip thickness ratio of aluminium at constant spindle speed of 180rev/min and depth of cut of 2 mm

Figures 2 and 3 give the effects of feed and depth of cut on chip compression. For all the oils tested the chip compression decreased gradually reaching a minimum and increased again forming a concave upwards in the first case. In the second case the reduction is gradual and tending to an asymptote. The reduction of chip compression with depth of cut were observed by previous investigators that upon an increase in the rate of feed, chip compression is reduced if there is no built-up-edge, and the reasons were summarized (Arshinov and Alekseev, 1973) as follows:

(a) Non-uniform stress distribution across the layer being cut leading to non-uniform deformation, that is, the nearer the layer being cut to the plane of cut or the thinner the layer, the more fully it is deformed and the higher the chip compression.
(b) The chip compression increases with a reduction in uncut chip thickness and the friction forces which additionally compress the chip have their greatest effect on the layer nearest to the surface of contact.
(c) The gradual rise after a minimum indicates the formation of a built-up-edge

Also when lubricants are used chips are thinner, meaning that a better lubricant should give a reduction in chip compression, and reduction of chip thickness with feed is an indication of reduction of cutting force, power consumed and temperature and that these depend on the cutting fluid used.

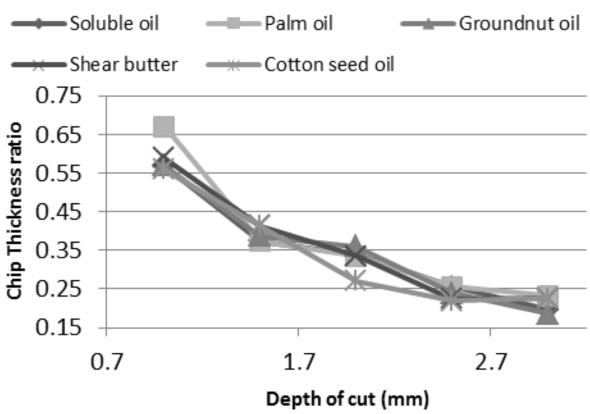

Figure 3: Effect of depth of cut on the chip thickness ratio for aluminium at constant feed rate of 0.5mmrev/min and spindle speed of 180 rev/min

Figure 4 shows a gradual decrease of surface roughness with increasing speed with all the lubricants investigated. Real situations in metal cutting are affected by built-up-edge (BUE) which forms on the rake face of the cutting tool. The crests on the characteristics in figure 2 could be interpreted as evidence of built-up-edge for each lubricant. When built-up-edge becomes negligibly small, the surface roughness corresponds to that produced by the 'feed marks' which is called 'ideal surface roughness' (Chilsom, 1958). As cutting speeds increase there is a deterioration of surface quality because the cutting fluids fly off the tool-work piece interface at high cutting speeds. The reaction time for the formation of chemical compound is too short and the time for the convection of heat developed at high cutting speeds is too short. As the speed is increased, a limit is reached above which no built-up-edge is formed. The shape of the tool improves with a corresponding improvement of the surface finish as the built-up-edge disappears. There is also a general increase of roughness with increasing feeds and increasing depths of cut.

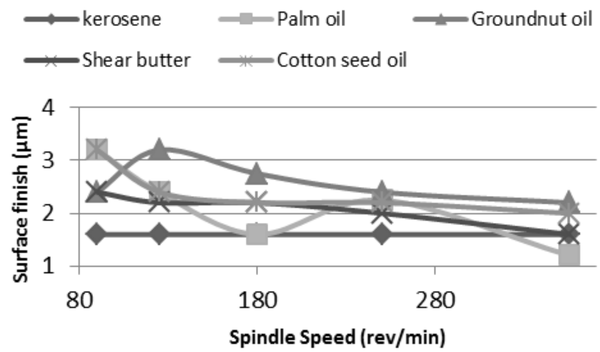

Figure 4: Effect of spindle speed on the surface roughness of aluminium at constant feed rate of 0.5 rev/mm and depth of cut of 2mm

The surface roughness increased with feed (Figure 5) and depth of cut (Figure 6). This is because higher feeds increase the cutting forces and temperature acting on the tool which consequently accelerate tool wear and hence affects the surface quality of the machined surface. For all the fluids tested the order of improving surface finish is: kerosene, sheabutter, palm oil, cotton seed and groundnut oil.

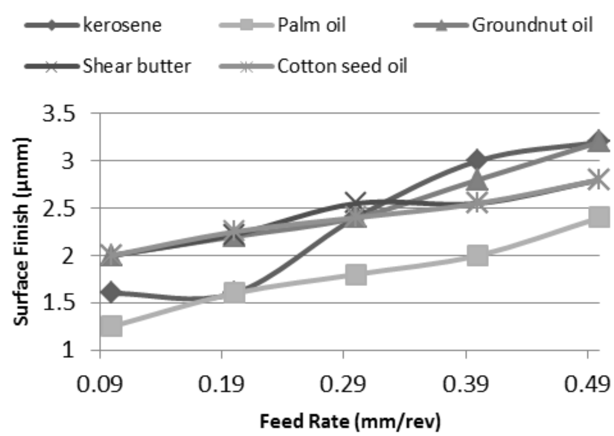

Figure 5: Effect of feed rate on the surface roughness of aluminium at constant spindle speed of 180 rev/min and depth of cut of 2mm

The temperature variations with speed, feed and depth of cut are given respectively in figures 7, 8 and 9 and in each case the temperature increased gradually with speed, feed and depth of cut. In an earlier work (Mishra, 1969) it was explained that cutting forces decrease with speed and that since quantity of heat is the product of force and velocity it follows that more heat will be generated with increase in speed. Also at low cutting speeds the principal factor affecting tool-chip interface temperature is the deformation at the shear

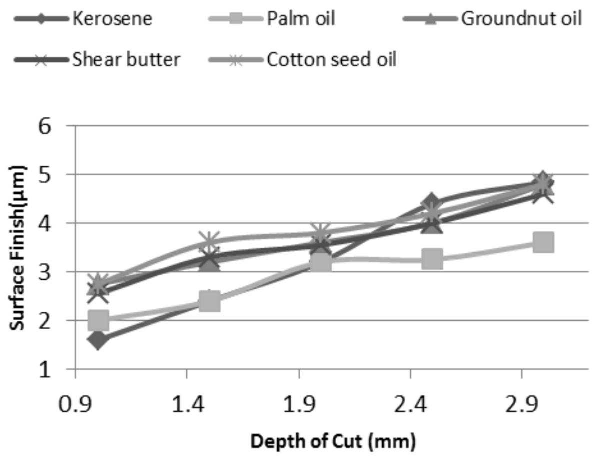

Figure 6: Effect of surface roughness on the depth of cut of aluminium at constant feed rate of 0.5rev/mm

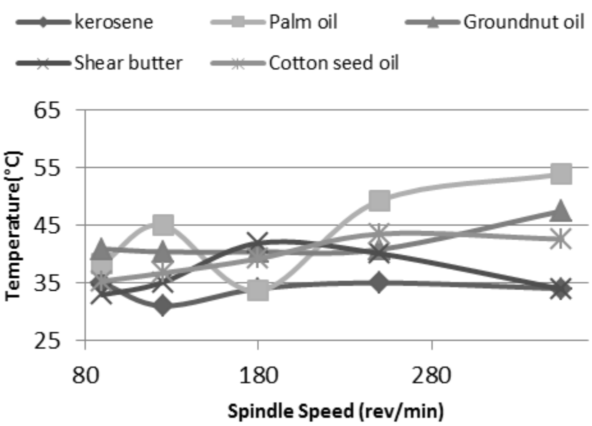

Figure 7: Effect of spindle speed on the surface temperature of aluminium at constant feed rate of 0.5rev/mm and depth of cut of 2mm

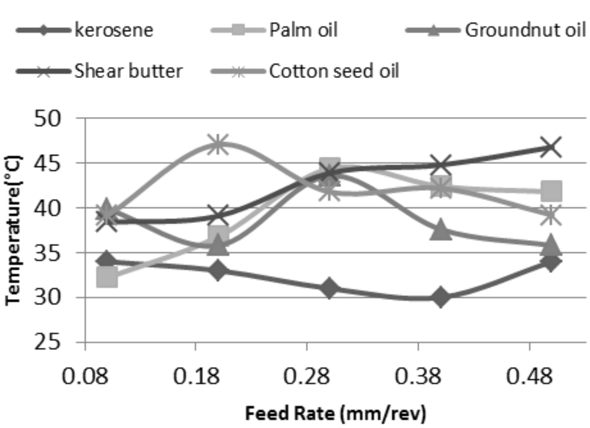

Figure 8: Effect of feed rate on the surface temperature of aluminium at constant spindle speed of 180rev/min and depth of cut of 2mm

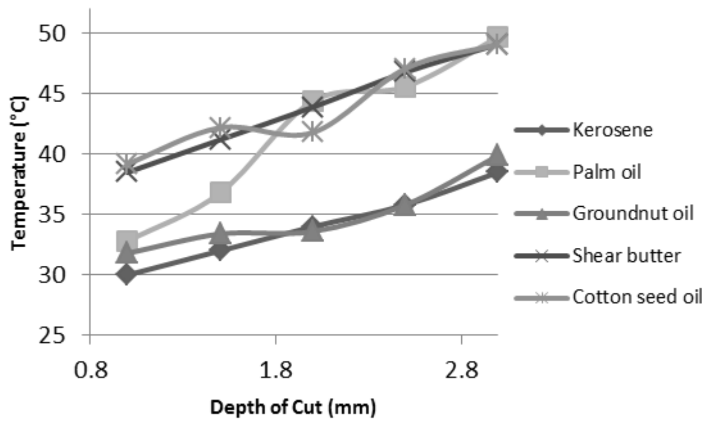

Figure 9: Effect of depth of cut on the surface temperature of aluminium at constant feed rate of 0.5 rev/mm and spindle speed of 180 rev/min

zone, while at high cutting speeds the tool-chip friction is the important factor in the interface temperature. Kerosene performed better than the vegetable based oils in terms of temperature reduction probably due its volatile nature which made penetration to the tool-work piece interface faster and hence better heat reduction. When the speed was varied, the order of the rate of heat reduction capability obtained in this work is kerosene, sheabutter, groundnut oil cottonseed oil and palm oil. Previous studies on cutting fluids have shown that the variation in their performance is associated with their chemical composition, for example, friction is lowered by oily fluids such as palm oil and there is a general decrease of coefficient of friction and hence power reduction resulting in a machined part with good surface finish.

The properties of vegetable oils which enhance their performance in machining operations include the presence of fatty acids (Ajala, 1982) which are effective as boundary lubricants due to chemical reaction between polar head of the acid molecule and the surface they react with, to produce the adsorbed layer which is sufficiently thick to separate the surfaces completely [Rowe, 1978] thereby reducing friction. The presence of surface active agents such as *stearic* acid and halogens like chlorine help to reduce surface energy and increase its wetting power or oiliness. Ajala (1982) has shown that *shea butter* contains 35% by weight of *stearic* acid as compared with groundnut oil and palm oil with percentage *stearic* contents of 4.5% and 4% respectively. Also Obi (2000) has shown that *sheabutter* contains 60.35 µg/g of *chlorine*, *groundnut oil* 11.91µg/g and *palm oil* 29.60µg/g. In addition the investigated oils have viscosities as follows: sheabutter 6.8 stokes, groundnut oil 5.5 stokes and palm oil 5.9 stokes. These properties have contributed to the satisfactory performance of these vegetable oils in machining.

IV. Conclusion

This work has shown the potentialities of locally sourced vegetable oil as machining lubricants for aluminium. Palm oil, groundnut oil, shear butter oil and cotton seed oil which are vegetable oil studied experimentally in the turning operation of aluminium under varying spindle speed, feed rate and depth of cut and compared with the conventional cutting fluid. The parameters investigated are the chip thickness ratio, surface finish and surface temperature and these properties were found to vary for different investigated lubricant. The properties of vegetable oils which enhance their performance in machining operations include the presence of fatty acids, surface active agents such as *stearic* acid and halogens such as chlorine, which help to reduce surface energy and increase its wetting power or oiliness.

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