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ASSESSMENT OF SUITABILITY OF VEGETABLE-BASED OILS AS CUTTING FLUIDS IN DRILLING OPERATION

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Abstract: The suitability of vegetable oils (palm oil, groundnut oil) as base oil in cutting fluid was examined in this study. The performance of these vegetable oil based cutting fluids compared with petroleum based "supa" oil and dry machining under varying spindle speeds, feed rates and depths of cut was carried out during drilling operation of mild steel on Computer Numeric Controlled (CNC) milling machines using a 10 mm HSS drill bit with a clearance angle 6º and point angle of 118º in an ambient environment of 29°C. The parameters measured are the chip thickness using micrometer screw gauge, temperature at the workpiece-tool interface using embedded thermocouple and viscosity with falling ball viscometer. Their performances when compared with the conventional petroleum-based oil have shown that they can perform similar functions based on their good lubricity, viscosity, cooling behaviour and wetting ability. Thus, the vegetable-oil based cutting fluids can serve as suitable alternative replacement for toxic, non-biodegradable conventional petroleum-based cutting fluids.
Keywords: vegetable oils, cutting fluid, machining, mild steel, viscosity

1. INTRODUCTION

Machining operations generate heat which usually results into high local temperatures between the tool and the work piece, and friction at the chip-tool interface. Thus, cutting fluids are used to provide lubrication for chip-tool contact and cool the cutting zone thereby eliminating or reducing the friction and also temperature generated (Byers, 1994). Cutting fluids also flush chips away from the cutting zone, protect the corrosion of the machined surface, improve the tool service life, reduced thermal deformation of work piece and give better surface finish (Rahman et al., 2002).

Traditionally, petroleum-based oils are widely used by the operators due to their suitable lubricating properties on both the workpiece and the cutting tools (Adegbuyi et al., 2010; Abdalla and Patel, 2006). However, petroleum-based oils have adverse health effects on users because they are carcinogens and can also cause skin eczema and oil acne. In addition, irritation of the respiratory tract can result from prolonged exposure to their mist. Growing demand for environmentally acceptable cutting fluids and the need for safety and health of users have encouraged research into the use of vegetable-based oils. These oils are renewable, non toxic, biodegradable and environmentally friendly (Honary, 2004). More so, petroleum-based oils are non-renewable and more expensive due to removal of oils subsidies while vegetable-based oils are renewable, readily available and relatively cheaper.

Vegetable oils are natural esters that are plant based products, which have varied chemical composition. According to Bennion, (1995), vegetable oils can be obtained from plant seeds, fruits, or nuts by different pressing methods, solvent extraction or a combination of these. Advantages for the use of vegetable oil include higher lubricity resulting in lower friction losses, high viscosity indices, which are about twice those of mineral oils and they also have low volatilities as manifested by their high flash points (Honary, 2004). Additionally, vegetable oils have good resistance to shear and little or no environmental hazards (Erhan et al., 2006). However, the major drawback in the application of vegetable oils as cutting fluid is the fact that in their natural forms, they lack sufficient oxidative stability and cold-temperature properties. Anti-oxidant, which refer to any type of chemical/natural agent which inhibits attack by oxygen or ozone (Scott, 1965), and other additives are added to vegetable oils in order to improve their oxidative stability and other drawbacks.

In this study, vegetable oils are being investigated to serve as alternative base oil in cutting fluids and other lubricants and possible replacement for non-biodegradable, toxic, petroleum-based oils, which are currently being used. The primary aim of the study is to evaluate the performance of vegetable-based oils (palm oil and groundnut oil) compared with that of mineral oil-based cutting fluid in mild steel machining.

2. MATERIALS AND METHOD

2.1. Materials

The materials used for this study include:

1. SGHI-8890 CNC milling machine of maximum speed of 12000 rpm and 15 kW drive motor
2. Cutting tool – 10 mm HSS drill bit with a clearance angle 6° and point angle of 118°
3. MS6500 K-Type digital thermocouple
4. Micro-meter screw gauge
5. Digital weighing balance
6. Ball viscosimeter
7. Mild steel plates of approximately 90 mm x 75 mm x15 mm in size

2.2. Preparation of the vegetable oil-based cutting fluids

Ground nut (Arachis hypogaea) and palm (Elaeis guineensis) oils were purchased in a local market within Ilorin metropolis and were then sieved to remove any foreign particles or dirt. 60 ml each of the oils were put in separate beakers, lightly heated on the burner to about 55°C and stirred to ensure thorough mixing with the additives added. The oil additives were emulsifier (9% Sodium Petroleum Sulphonate); anticorrosive (6% synthetic ester); bactericide (5% derivative of triazine, $C_3H_3N_3$); and, antioxidant (2% lemon extract). The performances of the vegetable-based oils are compared with that of petroleum-based cutting fluid with trade name "supa oil". The additives were mixed in the proportion shown in Table 1.

Table 1: Constituents of the cutting fluids.

Cutting Fluids	% Base Oil	% Additives	% Water	Total (%)
Groundnut oil	18	22	60	100
Palm oil	18	22	60	100

The emulsifier was added to prevent separation of water from oil, while the bactericide and anticorrosive were to impede action of biodegradable organism and act to prevent corrosion, respectively. The mixing was carried out at an elevated temperature of 55°C. The surfactant mixture was left in the laboratory for 3 days to allow time for optimum and desired assortment.

2.3. Chemical Composition of the Work piece

The chemical composition analysis of the steel sample was carried out using an optical electron spectrometer (OES). The results obtained are presented in Table 2.

Table 2: The chemical composition of the mild steel sample

Element	% composition	Element	% composition	Element	% composition
C	0.2422	P	0.0049	Cr	0.0104
Si	0.2020	Mn	0.7374	Mo	0.0011
S	0.0108	Ni	0.1067	V	0.0006
W	0.0065	Co	0.0002	Zn	0.0013
As	0.0005	Al	0.0013	Cu	0.0033
Sn	0.0022	Pb	0.0005	Fe	97.6824

2.4. Drilling of the mild steel samples

Drilling of the steel samples was carried out on 4 Computer Numeric Controlled (CNC) milling machines using a 10 mm HSS drill bit with a clearance angle 6° and point angle of 118° in an ambient environment of 29°C. Palm oil- and groundnut oil-based cutting fluids, petroleum-based (supa oil) were used as cutting fluids on three of the CNC machines, while dry machining was carried out on the fourth machine. 5 specimens were machined on each of the CNC machine. Each of the steel samples was mounted on the machine and drilled through thickness of 5mm, 10mm and then 15mm. The cutting fluids were applied through a double hose by flooding means. Timing was done using the stop watch where each cutting took 2.35 minutes, 4.22 minutes and 6.37 minutes for 5mm, 10mm and 15mm depth, respectively.

Temperature of each steel sample was taken during drilling with the aid of a K-type thermocouple embedded through a notched hole on the work piece side as shown in Figure 1. The thermocouple probes were located at depths 3mm, 8mm, and 12mm, respectively from the top of the workpiece. The distance between the thermocouple wire and the drilled hole was approximately 1.25 mm to prevent rubbing action between drill bit and the probes. The temperature of the workpieces were first measured on all the machines at a constant spindle speed of 95rev/min and feed rate of 0.25mm/rev with an embedded. Later the spindle speeds were varied. For chip thickness determination, machine speeds of 95rev/min and 160rev/min were used while the feed rate was kept at 0.25mm/rev.

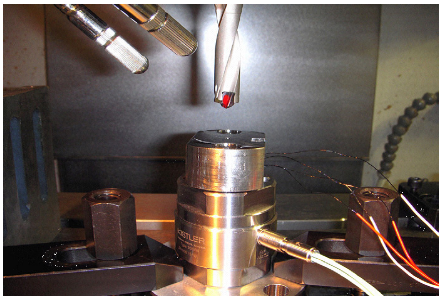

Figure 1: The drilling operation on CNC milling machine with an embedded thermocouple

Chip thickness was also measured immediately after drilling through the entire thickness using a micrometer screw gauge. The results are presented in Figure 3.

2.5. Determination of viscosity

Viscosity measures the fluid property which prevents it from flowing when subjected to an applied force. Fluid temperature was varied between 20ºC and 50ºC using conditioned and controlled environments at 5ºC intervals using falling ball viscometer (Figure 2). The relationship and behaviour of different cutting fluids were examined using the mathematical expression [20]:

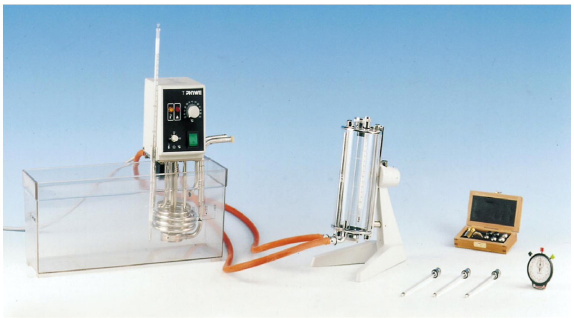

Figure 2. Viscosity measurements with falling ball viscometer

$$\eta = t\,(\rho_1 - \rho_2)\,k \qquad (1)$$

where, η is the dynamic viscosity (Pa. S or Poise), ρ_1 = ball density (g/cm^3), ρ_2 = fluid density (g/cm^3), t = fall time of ball between the two marks of tube and k is the ball constant.

A value of 0.13 Pa cm^3/g was used for k (Oliveira and Alves, 2006).

Densities of individual cutting fluids were determined using the mass/volume ratio after weighing and measuring. The results of variation of the various fluids' viscosities with surface temperature of the mild steel samples are presented in Figure 4.

3. RESULTS AND DISCUSSIONS

The temperature variation with depth of cut is given in Table 3, where it was revealed that the temperature increased gradually with depth of cut. The average temperature at the tool-workpieces interface increased with increased depth of cut for all the cutting fluids as well as dry machining. The results also showed that highest tool-workpiece interface temperature was constantly obtained during dry machining. This is possibly due to high friction between the tool and the workpiece. Hassan et al. (2006) submitted that the contact pressures between devices in close proximity and moving relative to each other are usually sufficient to cause surface wearing, frictions and generation of excessive heat without protector. These friction, wear and excessive heat have to be controlled by a process or technique called lubrication (Hassan et al. 2006).

Table 3 also reveals that the petroleum-based cutting fluid (supa oil) gave the least average temperature value as the depth of cut increases. However, due to its poor biodegradability (Salete and Oliveira, 2008) negative effects on the environment such as surface water and groundwater contamination, air pollution, soil contamination and consequently, agricultural product and food contamination including health of operators (Birova et al. 2002), groundnut oil with very close average value would be highly recommended. Wood (2005) revealed that groundnut oils compete favourably well and perform even better than the petroleum-based cutting fluids in the area of heat dissipation. He discovered that percentage specific heat capacity was about 105% as compared with mineral oil based of only about 88%. Specific heat capacities are direct functions of wettabilities (Xavior and Adithan, 2009) In addition, low viscosity of the groundnut oil (Figure 4) also suggests that they have capability of spreading more readily than other fluids. Cutting fluids are essentially applied to reduce heat generated by the tool and workpiece in order to improve the service life of the tool and also not to alter the microstructure of the workpiece. Hence groundnut oil has a potential to replace the mineral oil in metalworking processes.

Table 3: Effect of depth of cut on the surface temperature of mild steel at constant feed rate of 0.25 mm/rev and spindle speed of 95 rev/min.

Depth of cut (mm)	Temperature (°C)			
Vegetable-based oil	Groundnut oil	Palm oil	Supa oil	Dry Machining
5	72.58	76.08	70.78	97.42
10	76.14	86.00	73.44	102.44
15	78.98	89.24	76.66	109.96

The variation between the chip thickness and spindle speed at a constant feed rate of 0.25mm/rev and 15mm depth is shown in Figure 3. The figure revealed that the chip thickness decreased as the spindle speed increased from 95 rev/mm to 160 rev/mm for all the cutting fluids as well as dry machining. At low spindle speeds, a discontinuous chip is produced and cutting temperature is low since there is no built up edge. According to Rosenberg and Yeremin (1973), the spindle speed increases as the chip changes to inhomogeneous and continuous types. The temperature between the tool edge and workpiece also become high resulting into formation of hardened stagnant zone, which become welded onto the tool face. Figure 3 shows that the values obtained when palm oil was used as cutting fluid was the highest indicating high lubricating ability. The thick chips were most likely formed as a result of the better relative ease of slide between tool and workpiece with palm oil that has higher oiliness. Lawal et al. (2012) discovered that the impact of lubrication of palm oil with a reduction of 33.3% in coefficient of friction was noticed, when rake angle was varied for aluminium. In addition, it is noted that average thickness values of chips formed at a relative low spindle speed (95rev/min) are consistently higher than those obtained at 160rev/min except during dry machining. High values of chip thickness means better rate of metal removal and this is desirable to complete machining at a lesser time (Oliveira and Alves, 2006). Lowest chip thickness was obtained in dry machining due to high friction. Thus, cutting fluids greatly influence the size of chips that are formed during any metal working process. The low thickness of dry machined samples may be due to ease of fracturing as a result of striking of the chips with the workpiece. Although, this may be advantageous if the target is to obtain chips that would not tangle with cutting tool. However, balance has to be made to choose between quick machining and operator safety (Kaminski and Alvelid, 2000)

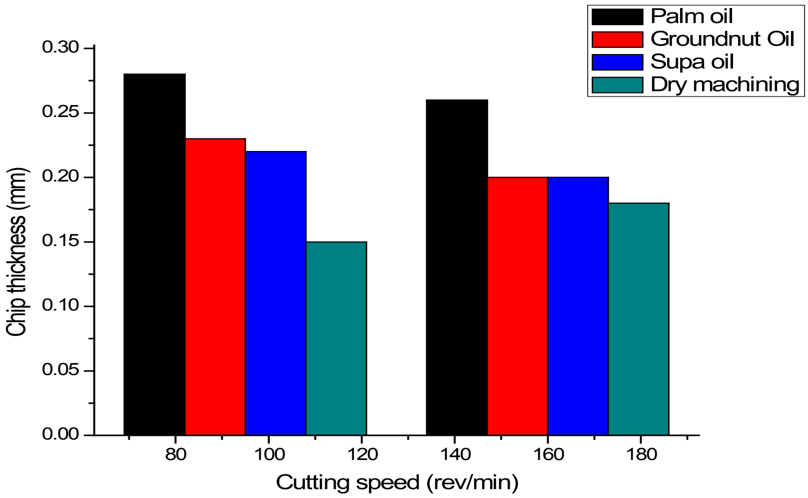

Figure 3: Variation in chip thickness and spindle speed at a constant feed rate of 0.25mm/rev and 15mm depth using different cutting fluids and dry machining.

The variation of the different cutting fluids viscosity with temperature is given in Figure 4. As shown in the Figure, machining with groundnut oil gave lowest average viscosity value, which is slightly lower than the value obtained with conventional petroleum-based oil. High viscosity value denotes the ability of the cutting fluid to prevent metal to metal (wear) contact, while low value may determine its ability for heat dissipation (Adejuyigbe and Ayodeji, 2000). Thus, groundnut oil will be more suitable in machining operation in order to prevent workpiece-tool wear which is highly desirable. Salate and Joao (2008) reported that high lubricating ability is a direct function of high viscosity. In addition, Abou-El-Hossein (2008) observed that the viscosity value of groundnut oil at 38°C is 228 Pa.sec which is reasonably close and in agreement with the result in the current study.

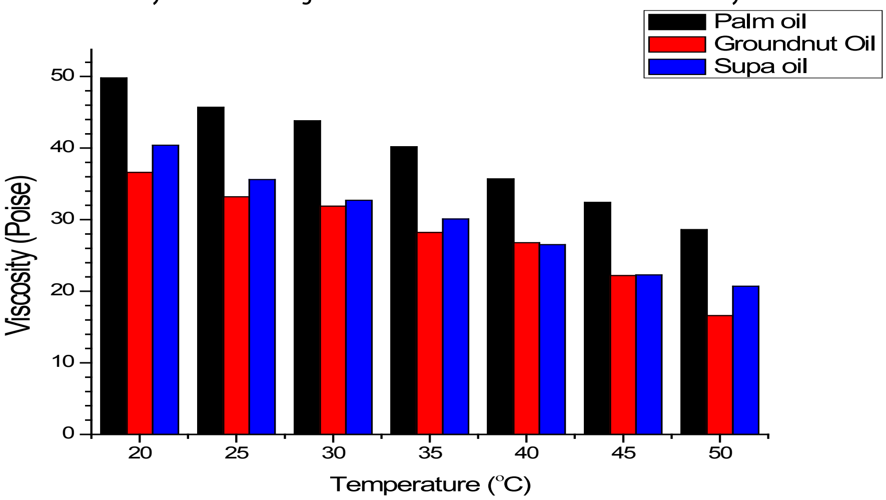

Figure 4: Effect of viscosity on the surface temperature of mild steel at constant feed rate of 0.25 mm/rev and spindle speed of 95 rev/min (Conversion: 10 Poise = 1 Pa.s [8]).

Effect of spindle speed on the temperature of the workpiece at constant feed rate of 0.25rev/mm and depth of cut of 15 mm is shown in Figure 5. The curves showed that the temperature at the tool-workpiece gradually increase with increased spindle speed indicating that more heat is generated at the higher spindle speed. Although, at the initial stage up to spindle speed of 125 rev/min, the temperature variation remain relatively constant possibly due to the cooling effect of the cutting fluids. Thus, optimum machining that will improve the tool service life and better workpiece surface finish can be best obtained at lower cutting parameters such as low spindle speed, feed rates and depth of cut with appropriate cutting fluid. This observation is in agreement with the results of Ojolo et al., (2008), Norrby (2003), Sreejith and Ngoi (2000), which revealed that using lowest machining parameters in conjunction with appropriate cutting fluids, will improve the tool service.

Temperature at the workpiece-tool interface is higher when cutting fluid is not applied, that is, in dry machining, compared with when cutting fluids were applied. The temperature variation is lowest with the application of groundnut based vegetable oil. This was closely followed by petroleum based “supa” oil temperature with palm oil based cutting fluid giving highest temperature value at all the spindle speeds. Salete et al. (2008) attributed this phenomenon to the difference in the cutting fluids wettabilities. It can be thus be inferred from the results that groundnut oil-based cutting fluid has better wettability, which is very close to that of the petroleum-based “supa” oil at all the investigated spindle speed. In addition, groundnut oil-based cutting fluid has been shown to have better thermal stability due to its higher viscosity index which makes it more fluidic at high temperature using higher spindle speed (Figure 4). The viscosity of the groundnut oil-based cutting fluid is more stable than that of petroleum-based lubricant as shown in Figure 4.

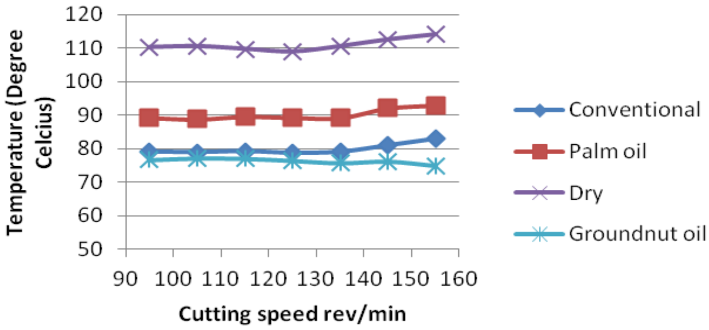

Figure 5: Effect of spindle speed on the workpiece temperature at constant feed rate of 0.25rev/mm and depth of cut of 15 mm.

In addition, the performance of bio-oils cutting fluids may be dependent on the workpiece material as reported by Lawal et al., (2012). Groundnut oil, they discovered, exhibited the highest reduction in cutting force when aluminum was turned at a speed of 8.25 m/min and feeds of 0.10, 0.15 and 0.20 mm/rev, respectively. Palm kernel oil had the best result when copper was turned at feed lower than 0.15 mm/rev. However, at higher feeds, groundnut oil had the best result for copper. They concluded that groundnut oil and palm kernel oils were effective in reducing cutting forces to prolong tool lives. Groundnut oil competitive performances with the conventional oil may probably be due to its good viscosity even at higher temperatures.

4. CONCLUSIONS

The results from this study have shown that vegetable oil-based cutting fluids have potentials to replace the non-biodegradable and toxic petroleum based cutting fluids. Groundnut oil-based cutting fluid displayed better cooling properties in terms of viscosity, lubricity and wetability that compared favourably with those of the conventional petroleum-based lubricants. The cooling property of the vegetable-based cutting fluids offers a competitive performance with that of conventional mineral-based oil, and thus can successfully replace the petroleum based cutting fluids. In addition, the results obtained in machining using palm oil as the cutting fluid also gave the highest value in chip thickness removed during drilling. These suggest that the environmentally friendly oils can perform competitively well with their ‘environmentally-harmful’ counterparts.

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