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Performance Evaluation of Vegetable Oil-Based Cutting Fluids in Mild Steel Machining

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Abstract

Vegetable oils are being investigated to serve as a possible replacement for non-biodegradable mineral oils, which are currently being used as base oil in cutting fluids during machining processes. In this present study, the performances of palm oil and groundnut oil were compared with that of mineral oil-based cutting fluid during machining operation of mild steel. Temperature of the workpieces as well as their chip formation rates using these vegetable oils as cutting fluids under different cutting speed (rev/min), feed rate (mm/rev) and depth of cut (mm) were compared with that of mineral oil and dry machining. The average temperatures of the workpieces were obtained at different depths of cut; 5mm, 10mm and 15mm under different cutting conditions. The temperature of the workpiece when groundnut oil was used as the cutting fluid was very close to that of the conventional oil, which was the lowest. Palm oil gave the overall highest chip thickness of 0.27 mm probably due to its better lubricating property. This was followed by that of the groundnut oil and the conventional oil as compared with dry machining of 0.17 mm thickness. Vitamin-C- rich-lemon fruit extract was used as an antioxidant to improve the oxidative stability of the vegetable oils. Viscosities of the various fluids were also analysed, and lowest average viscosity value of 28.0 Poise was obtained using groundnut oil. This shows that groundnut oil possesses better fluidity and faster cooling capacity than other oil samples. Samples lubricated with mineral-oil based fluid show fine microstructures, similar to what obtained using groundnut oil based cutting fluid. Fine surface morphology indicates improved surface roughness compared to using other cutting fluids. Based on these results, groundnut oil and palm oil are being recommended as viable alternative lubricants to the mineral oil during machining of mild steel.

Keywords: Vegetable oils, cutting fluids, drilling operation, mild steel, coolants.

1. Introduction

Mineral oils have been in use as the traditional source of cutting fluids in machining a number of metals and alloys because of their suitable lubricating properties on both the workpiece and the cutting tools (Adegbuyi et al., 2010; Abdalla and Patel, 2006). However, there are now myriad of challenges posed by using such oils as lubricants in most of today's application. Growing environmental concerns such as renewability, biodegradability, safety and health of operators demand serious attention (Abdalla and Patel, 2006). As shown in Figure 1 (Lawal et al., 2012), the price of mineral oil product seems lower compared with the market prices of natural/vegetable oil products but biodegradability, availability and numerous benefits of other by-products of the natural/vegetable oils have made them more suitable and economical to use. Furthermore, the recent economic reality in most countries due to high prices of petroleum products is also a motivating factor for the present work in that petroleum-based cutting fluids are themselves limited resources. In Nigeria, for example, the government has recently announced partial removal of oil subsidies, which automatically translated into increased petroleum products prices thus informing the need for an alternative source of cutting fluids.

Vegetable oils are plant based products, which are reared and refined for specific performance properties and other requirements. Recent studies have shown that bio-based cutting fluids have better lubricities and their viscosities reduce significantly well at high temperature than the mineral oil-based oils (Adejuyigbe and Ayodeji, 2000). In addition, vegetable oil-based cutting fluids have reduced overall volume of fluids used for lubrication due to their higher viscosity compared to the mineral oils based fluids. Mineral oils are petroleum based cutting fluids, which are easily obtainable in markets and are relatively excellent lubricants, but their continuous usage in machining will pose environmental contamination and health problems to operators (Adejuyigbe and Ayodeji, 2000). Thus, the use of vegetable oil-based cutting fluids (VBCFs) will be significant to systematically overcome these limitations and thus be a suitable alternative to mineral oil-based cutting fluids.

There are few challenges associated with the use of vegetable oils as cutting fluids. These include their low temperature viscosities, problems of oxidative and hydrolytic instabilities associated with the triglycerides naturally present in them (Adejuyigbe and Ayodeji, 2000). These triglycerides are present in vegetable oils as free fatty acids (FFA) (Oloyede, 2005). The effect of these FFA can be neutralised by an effective antioxidant (Adejuyigbe and Ayodeji, 2000) which may be used as additives. This justifies the use of environmentally-friendly antioxidants, vitamin C rich lemon extract, used as an additive in the present study in order to promote the culture of a green and safe ecology.

The primary aim of applying cutting fluids during machining is to eliminate, overcome or at least reduce the heat generation effect, friction and corrosion of both the tool and the workpiece (Nagpal, 2004). Their resulting positive effects include prompt heat removal, lubrication on the chip-tool interface and chip removal by constantly cleaning the machined zone (Aluyor et al., 2009). Heat is generated and built-up at the region between the tool's rake and/or flank faces and the workpiece by the action of rubbing together of the tool and workpiece. This may lead to generation of tensile residual stresses and micro cracks at the material surface (Petterson, 2007). Frictional energy develops between the duo which leads to rapid tool wear and reduction in tool life.

As cutting fluid is applied during machining operations, it removes heat by carrying it away from the cutting tool/workpiece interface. This cooling effect prevents tools and workpiece from exceeding their critical temperature range beyond which the tool softens and wears rapidly. Fluids also lubricate the cutting tool/workpiece interface, minimizing the amount of heat generated by friction. A fluid's cooling and lubrication properties are critical in decreasing tool wear and extending tool life (Petterson, 2007). Cooling and lubrication are also important in achieving the desired size, finish and shape of the workpiece. No one particular fluid has cooling and lubrication properties suitable for every metalworking application. Straight oils provide the best lubrication but poor cooling capacities. Water, on the other hand, is an effective cooling agent, removing heat 2.5 times more rapidly than oil. Water is a very poor lubricant when used alone and causes rusting. Soluble oils or chemicals that improve lubrication prevent corrosion and provide other essential qualities must be added in order to transform water into a good metalworking fluid (Petterson, 2007).

The sustainability of the use of cutting fluids and other lubricants can be divided into two aspects (Salete and Joao, 2008). The first aspect is about the origin of the resources, which can either be fossil or renewable raw materials, such as mineral oils and vegetable oils, respectively. The other aspect examines the environmental pollution associated with use and discharge of these products. The carbon cycles of mineral oil based products are not closed, but open. This leads to an increase in content of atmospheric carbon dioxide and thus contribute to global warming, an issue of concern to the entire globe. Contrary to mineral based oils, the carbon cycle of products of renewable resources (vegetable oils) is closed. The amount of carbon dioxide liberated during disintegration of organic chemicals equals the amount of carbon dioxide that was originally taken up by the plants from the atmosphere as shown in Figure 2 (Salete and Joao, 2008).
Figure 2 shows that the activity begins when photosynthesizing plants use up the carbon dioxide found in the atmosphere or dissolved water by the process of *assimilation*. These plants are then used in *production* of renewable oils (such as groundnut and palm oils) in industries. Such vegetable oils are processed (*i.e. formulation*) for onward production of drilling fluids which are easily recycled even by disposing into the soil again (*disintegration*).

2. Materials and methodology

The materials and equipment used in carrying out this work included 20 pieces of mild steel plate samples of 90 mm x 75 mm x15 mm in dimension, groundnut oil, palm oil, mineral oil-based cutting fluid (under trade name: 'supa oil'). Beakers graded in (ml), SGHI-8890 CNC milling machine of maximum speed of 12000 rpm and 15 kW drive motor, optical electron microscope (OEM) Model Number JEOL JEM 1200 EX, MS6500 K-Type digital thermocouple, stop watch, ball viscosimeter, Bunsen burner, stirrer, ice block, micrometer screw gauge, mesh sieve, 4 litre gallon of water, electric juice extractor, lemon fruits and digital weighing balance.

2.1 Preparation of the Vegetable Oil-Based Cutting Fluids

Oils of palm nut (Elaeis guineensis) and ground nut (Arachis hypogaea) were purchased in a local market in Kwara state, Nigeria. The local oils were sieved to remove any foreign particles or dirt. The additives were mixed in the proportion shown in Table 1.

The emulsifier (sodium petroleum sulphonate) was added to prevent separation of water from oil. The mixing was carried out at an elevated temperature of 55^oC. Juice was extracted from the lemon fruits and the extract was immediately added to the prepared samples. The lemon fruit was used because of its high vitamin C content to serve as possible antioxidant. Bactericide (5% of total mix) was added to impede action of biodegradable organism, while anticorrosive (6 % of total mix) was added to prevent corrosion. The surfactant mixture was left in the laboratory for 3 days to allow time for optimum and desired assortment.

2.2 Chemical composition of the workpiece material

Chemical analysis of the steel sample was carried out using an optical electron spectrometer (OES). The result obtained is presented in Table 2.

2.3 Machining of the mild steel samples

Drilling of the steel samples was done using 4 different Computer Numeric Controlled (CNC) milling machines at an ambient environment of 29^oC. 4 specimens were machined on each of the machine. The temperature of the workpieces were first measured on all the machines at a constant cutting speed of 95rev/min and feed rate of 0.25mm/rev. Later the cutting 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. A 10 mm HSS drill bit with a clearance angle 6^o and point angle of 118^o was used (Fig 3).

Palm oil, groundnut oil and 'supa oil' were used as cutting fluids on three of the CNC machines, while dry machining was carried out on the fourth 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. Temperature of each steel sample was taken during drilling with the aid of a K-type thermocouple embedded through a notched hole on the workpiece side as shown in Figure 4.

The thermocouple probes were located at depths of 3mm, 8mm and 12mm from the top of the workpiece. The distance between the thermocouple wire to the drilled hole wall was approximately 1.25 mm to prevent rubbing action between drill bit and the probes.

Chip thickness was also measured immediately after drilling through the entire thickness using a micrometer screw gauge. The results are presented in Figure 5 and Table 3.

2.4 Determination of viscosity

Viscosity measures the fluid property which prevents it from flowing when subjected to an applied force (Krahenbuhl, 2002). Fluid temperature was varied between 20°C and 50°C using conditioned and controlled environments at 5°C intervals. The relationship and behaviour of different cutting fluids were examined using the mathematical expression given in Equation 1 (Salete and Joao, 2008):

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

where η is the dynamic viscosity (Pa. S or Poise), ρ_1 is the ball density (g/cm^3), ρ_2 is the fluid density (g/cm^3), and t is the 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 (Salete and Joao, 2008). Densities of individual cutting fluids were determined using the mass/volume ratio after weighing and measuring. The results of the viscosities are as shown in Table 4.

3. Results and discussions

Figure 5 shows the variation of temperature of the workpiece with depths of cut using different cutting fluids at ambient temperature of 29°C. 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. The results revealed that highest workpiece temperature was constantly obtained during dry machining. This is possibly due to high friction between the tool and workpiece. Hassan et al. (2006) opined 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. The extent of the workpiece wear is also evident in the micrograph obtained for the dry-machined workpiece (Figure 13). These friction, wear and excessive heat have to be controlled by a process or technique called lubrication (Hassan et al., 2006).

Figure 5 also reveals that the mineral oil-based conventional cutting fluid gave the least average temperature value. However, due to its poor biodegradability (Salete and Joao, 2008), and 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. Norrby (2003) revealed that groundnut oil compete favourably well and perform even better than the mineral oil-based cutting fluids in the area of heat dissipation. They discovered that percentage specific heat capacity of groundnut based cutting fluid was about 105% as compared with that of mineral oil based of only about 88%. Specific heat capacities are direct function of wettabilities (Xavior and Adithan, 2009). In addition, low viscosity of the groundnut oil (Table 4) also suggests that they have capability of spreading more readily than other fluids.

The average temperature of the workpieces increased with increased drill depth for all the cutting fluids as well as dry machining even within the errors. Temperature generation is highest for all workpiece samples when depth of cut is highest (i.e. 15 mm) although the error bars revealed very similar temperature at both 10 mm and 15 mm when the vegetable oils were used as cutting fluids. Thus, it is opined that the workpiece temperature and time of cut would increase with increasing depth of cut. 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 shows the chip thickness using different cutting conditions and cutting parameters (i.e. speed and feed rate). On the overall, 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 cutting 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 (Krahenbuhl, 2002). Lowest chip thickness was obtained in dry machining due to high friction. The low thickness of dry machined samples may also 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). Thus, cutting fluids greatly influence the size of chips that are formed during any metal working process. These results also revealed that the change in cutting speed has a significant effect on the workpiece temperature. In addition, an increase in cutting speed is always accompanied by a reduction in chip thickness as shown in Table 3.

The variation of the different cutting fluids viscosity with temperature is given in Table 4. As shown in the table, machining with groundnut oil gave lowest average viscosity value, which is slightly lower than the value obtained with conventional 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 (Hong and Broomer, 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, Norrby (2003) observed that the viscosity value of groundnut oil at 38^{o}C is 228 Pa.sec which is reasonably close and in agreement with the result in the current study (Table 4).

Variation of temperature of the workpiece under different cutting speed is shown in Figure 6. The trend of all the curves is such that low cutting speeds lead to minimal temperature value (heat) generation. It can therefore be inferred that to minimize energy consumption, low cutting speed and feed rates must be used. In addition, all cutting parameters must be selected at their low levels to obtain optimum machining and maximum tool life. Ojolo et al. (2008), Norrby (2003), Sreejith and Ngoi (2000) have also shown that using lowest machining parameters in conjunction with appropriate cutting fluids will improve the tool service. Compared to other fluids, the results also showed that the nature of temperature variation is highest in dry machining while conventional coolant temperature variation is lowest. However, similar trend was followed with the use of conventional fluid and groundnut based oil. The temperature of the workpiece was also found to remain constant with increased speed of cutting showing the heat dissipating capacity of the coolants. Palm oil gave highest compared with other fluids at higher cutting speed which suggests that performance at high temperature is lower than all other fluids. However, at cutting speeds greater than 135rev/min, groundnut oil out-performed the conventional oil in temperature lowering at the work zone. Salete and Joao (2008) attributed this phenomenon to the difference in the cutting fluids wettabilities. Thus, it can be infered that groundnut oil and the conventional oil may have had almost the same wettabilities at lower cutting speeds, but there is better perceived thermal stability of groundnut oil due to its higher viscosity index which makes it more fluidic at high temperature using higher cutting speed (Table 4). Ability of the groundnut oil based lubricant to cool the work zone faster than every other sample may be due the higher cutting speed, which translates to increase in heat produced. The viscosity of the groundnut oil is more stable than that of conventional lubricant as seen in the narrow difference at different cutting fluids temperature (Table 4). That means the change of viscosity is small by the influence of high temperature and thus satisfies their use as lubricating oils at very high temperature.

In addition, cutting fluids performances vary from material to material. For instance, Lawal et al. (2012) reported that the effects of the bio-oils on cutting force were material dependent. Groundnut oil, they discovered, exhibited the highest reduction in cutting force when aluminium 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.

3.1 Morphologies of the samples under different cutting environment

Surface morphologies of four different mild steel samples drilled under the four different cutting environments were observed under an optical microscope. The drilled samples were sliced into two halves, surfaces ground using silicon carbide and polished with mercury paste. Then, they were etched using potassium nitrate (for 30 seconds) and later immersed in ethanol (for 20 seconds). Fan drying was done after which they were taken to dark room for optical examination. Figures 7 - 10 show the optical micrographs of the sample surfaces.

Figures 7 and 8 show the smooth surface finishes obtained using the mineral oil-based cutting and groundnut oil-based fluids for drilling mild steel specimen. Maximum surface roughness is, however, obtained under a dry-machined specimen as shown in Figure 10.

Surface quality here is therefore a measure that lies in between the two above mentioned extreme environments. Smoothness obtained when drilling under a groundnut oil-based cutting fluid is close to that of a mineral oil-based cutting fluid. This is an indication of the excellent lubricating properties of groundnut oil-based lubricant. Ezugwu et al. (2004) reported that vegetable oils are known to provide excellent lubricity due to the trigycerol that attaches to the metal surface. This allows a monolayer film formation with the non-polar fatty acid chains and consequently leads to an easy sliding contact. The effortless interaction on the surfaces of workpiece and tool led to the plane and even surface geometry. Belluco and De Chiffre (2004) also agreed that vegetable oil-based cutting fluids give better surface finish than mineral oils because comparative minimal cutting force is generated when the latter was used. In another study, they investigated tool life, tool wear, chip formation and cutting forces as performance criteria and results were better with vegetable cutting oil than that of the mineral cutting fluid because tool life was increased by 177% as a result of reduced tool wear, and thrust force was reduced by 7%. Reduction in tool wear is an indication of decreased surface roughness. This is in agreement with the findings in this work. The fine lamellar structures indicated that the mineral-oil machined specimen gave good surface finish than the other two samples vegetable oil-based machined specimens (i.e. palm oil and palm-oil/groundnut oil mixture). However, the structure obtained by a groundnut-oil based cutting is even better and finer that of the mineral oil. This is also in agreement with the conclusions drawn by Shokrani et al. (2012), and Belluco and De Chiffre (2004) that the application of VBCFs gave better surface finish when compared with commercial mineral oil-based cutting fluids, MCFs.

The micrograph of palm oil-based machined sample (Figure 9) suggests that the surface of the machined specimen here is more rough and 'spongy'. The structure obtained is not as fine as that of using groundnut oil- and mineral oil-based cutting fluids. Palm oil based cutting fluid have lower capacity of lubricating both the tool and workpiece as shown in Figure 9, where higher feed lead to generation of more heat energy as opposed to reduced heat energy generated in using mineral oil and groundnut oil. The more heat generated will lead to more uneven surface produced. The perceived mild roughness in the palm oil-based cutting fluid is also a function of its relative lower thermal conductivity. This leads to formation of chips at higher temperatures making possible the growth of larger side burns during each grain scratch. This is probably as a result of the higher viscosity of palm oil than the groundnut oil, thus making it displaying more of the properties of the palm oil-based cutting fluid.

However, that of palm-oil based cutting fluid shows more of white patches which may be indicative of more graphite flakes present. Graphite's presence is significant especially in the cutting tools because they aid wear and abrasion resistance because of their hardness. This hardness is probably the reason why it took comparably more time in drilling under palm oil based fluid than others except for dry machining. Figure 10 shows the micrograph of dry-machined specimen. Alternate white and dark patches are evident on the machined surface. During drilling, the workpiece material was crushed between the tool–workpiece interface, which was mainly attributed to the high strain rate during the deformation process. Subsequently, part of the workpiece flowed between the cutting edge and workpiece, causing abrasive flank wear. Uniform flank wear, micro-chipping, micro-cracking and flaking were found to dominate this operation. This is believed to have occurred because the tool experienced interrupted contact or impact during the drilling process, inducing fluctuation of thermal and mechanical stresses, which caused micro-chipping and flaking. This confirms the absence of other phases that may be possibly seen in a cutting fluid environment because of the alternate heating and rapid cooling. The morphology of the dry-machined specimen showed only a combination of white dotted area and black.

4. Conclusions

It has been established that ecology-friendly vegetable-based oils could successfully replace petroleum-based mineral oils as cutting fluids. With slight modifications and deliberate but careful alterations in some of the components of such oils, even better performing cutting fluids could be obtained. The overall results are summarised below:

- The cooling property of vegetable-based cutting fluids offers a competitive performance with that of conventional mineral-based oil, as shown by the narrow temperature difference between the values obtained using groundnut oil and that of mineral-based oil.
- The chips thickness formed using palm oil as cutting fluid was highest, probably due to its better lubricating ability, especially at elevated temperature. This allows easier and deeper penetration of cutting tool into workpiece and better metal removal rate.
- Viscosity of groundnut oil-based sample was lowest and the range was closest even at very high temperature. Low viscosity means high viscosity index and the tendency to be fluidic at high value of working temperature.
- Oxidative instability of the vegetable oil-based cutting fluid is controllable by using the "nature-friendly, uncomplicated and less-mineralised solution as obtained in the used lemon fruit extract antioxidant to cater for the problem of the chlorinated, sulphurised and phosphorus-based types used which are known to cause health issues to operator common to mineral based oils.
- Dry machining is more time consuming than machining using any form of cutting fluids probably due reduced tool performance in the absence of cutting fluids.
- The micrograph in machining with groundnut oil sample gave competitive result of finest and smoothest view as compared with mineral oil-based sample. This is an indication good surface roughness. Better surface finish shows that there is lesser friction and wear between tool and workpiece.

5. Acknowledgements

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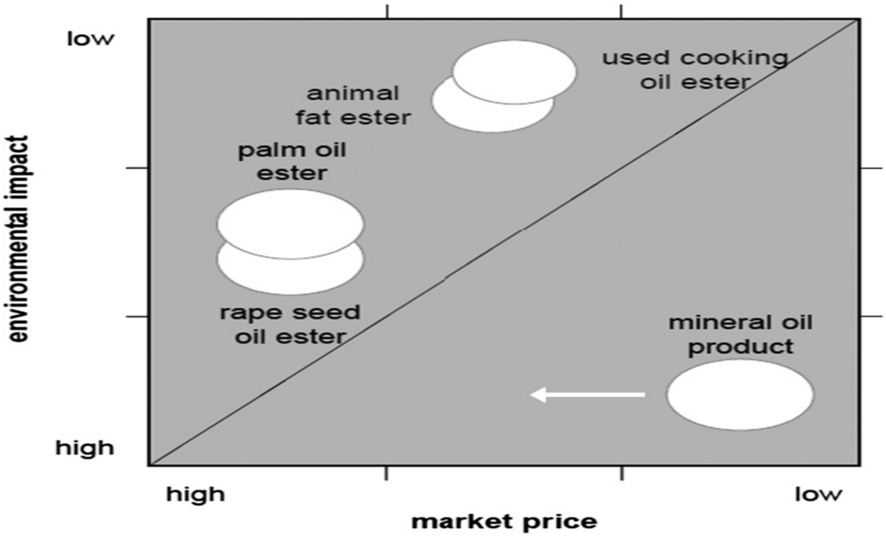

Figure 1: Market prices versus environmental impact inter play [12].

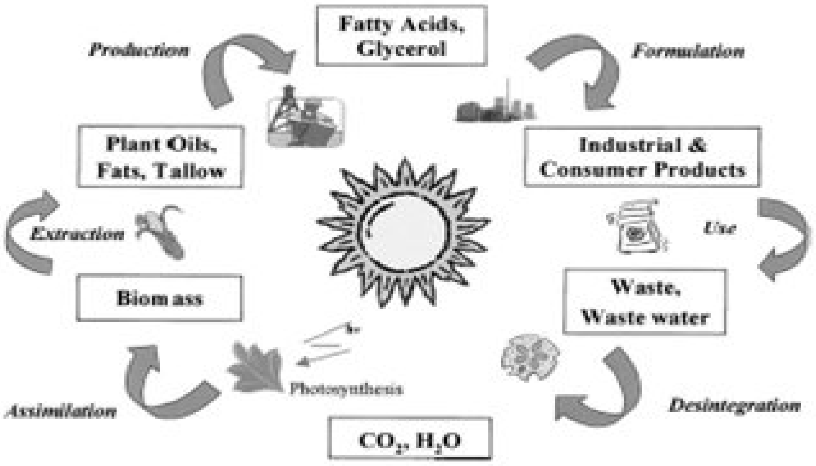

Figure 2: The life cycle of renewable resources used in cutting fluids [18].

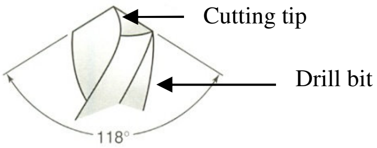

Fig 3: Sketch of cutting tip of drill bit with point angle 118^{o}.

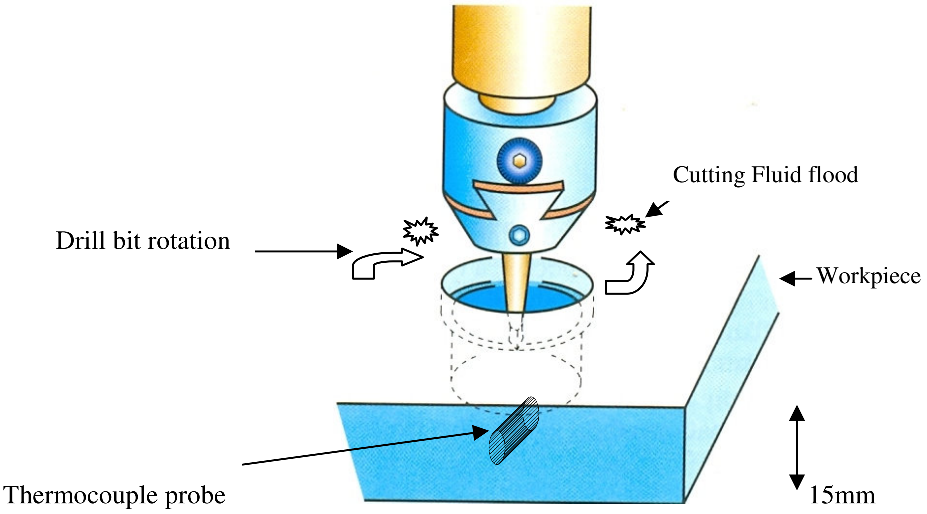

Figure 4: Schematic drawing of the drilling operation with a thermocouple embedded.

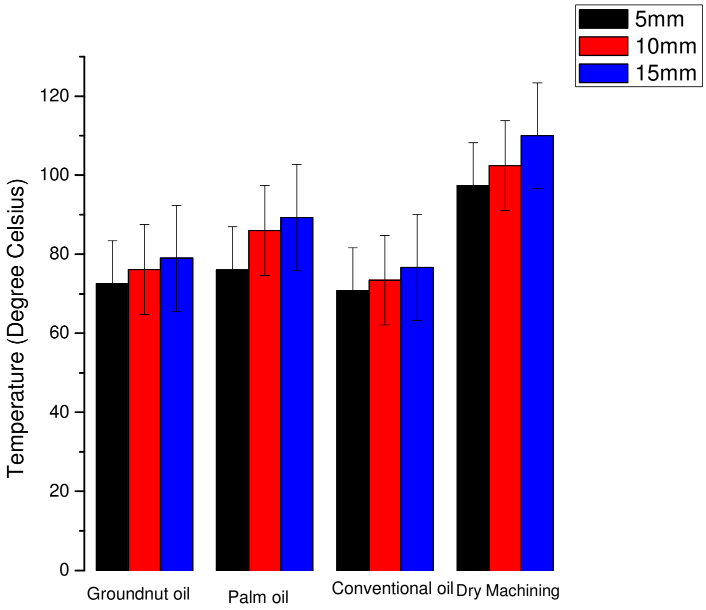

Figure 5: Work pieces temperature at cutting speed 95rev/min and feed rate 0.25mm/rev under different cutting fluids at varying depths of cut.

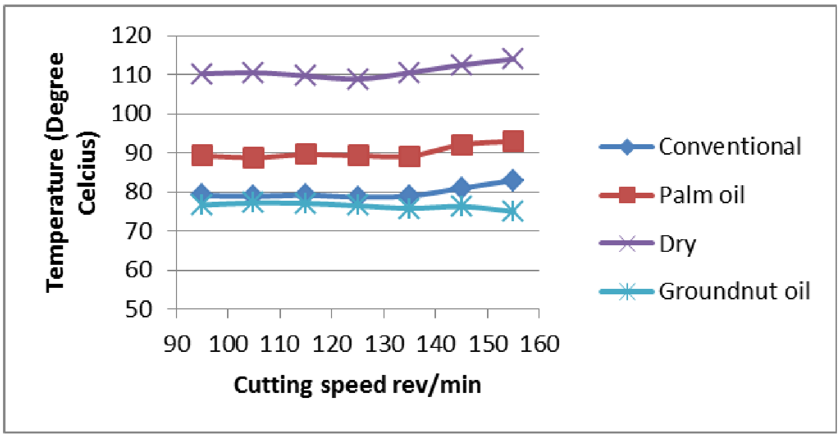

Figure 6: Work pieces temperature at feed rate of 0.25 mm/rev and 15 mm depth of cut with varying cutting speed and cutting fluids.

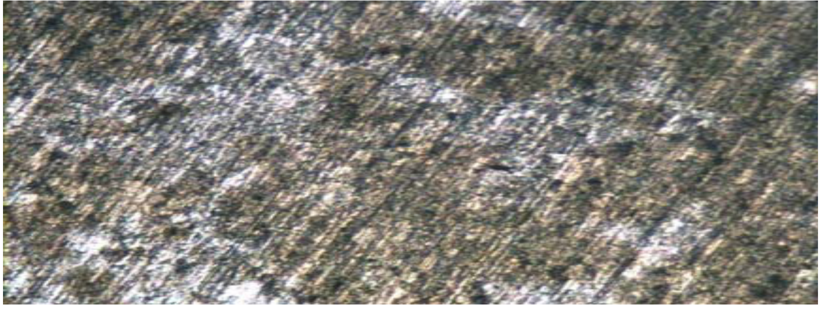

Figure 7: Micrograph of specimen drilled using 'supa-oil' cutting fluid (X 200)

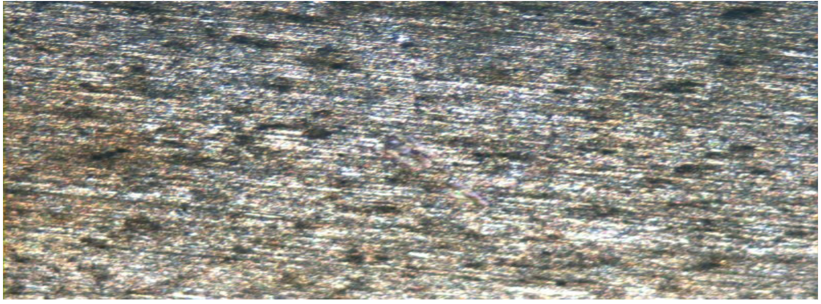

Figure 8: Micrograph of specimen drilled using groundnut oil-based cutting fluid (X200).

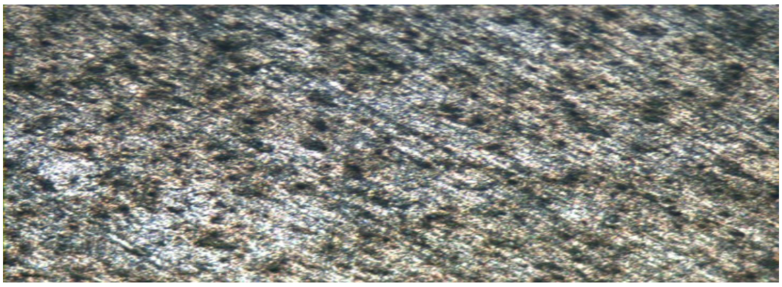

Figure 9: Micrograph of specimen drilled using palm oil-based cutting fluid (X200).

Figure 10: Micrograph of dry-machined specimen (X200).

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
Mixture (ratio)	18 (9:9)	22	60	100

Table 2: Chemical Composition of the mild steel sample (wt. %)

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

Table 3: Variation in chip thickness using different cutting fluids and parameters.

Cutting Fluids	Chip thickness (mm) at 95rev/min, 0.25mm/rev, 15mm depth	Chip thickness (mm) at 160rev/min, 0.25mm/rev, 15mm depth
Palm oil	0.28	0.26
Groundnut oil	0.23	0.20
Mixture	0.25	0.21
Conventional oil	0.22	0.20
Dry machining	0.15	0.18

Table 4: Viscosity variation with temperature of the different cutting fluids.

S/No	Temperature (^{o}C) of cutting fluids	Mixture (A) Viscosity (Poise)	Palm oil (B) Viscosity (Poise)	G/nut oil (C) Viscosity (Poise)	Conventional oil (D) Viscosity (Poise)
1	20	46.7	49.8	36.6	40.4
2	25	43.3	45.7	33.2	35.6
3	30	38.9	43.8	31.9	32.7
4	35	31.5	40.2	28.2	30.1
5	40	30.2	35.7	26.8	26.5
6	45	27.2	32.4	22.2	22.3
7	50	23.7	28.6	16.6	20.7
8	AVERAGE	34.5	39.5	28.0	29.8

***Conversion: 10 Poise = 1 Pa.s [8]

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