EFFECTS OF NEEM OIL AS CUTTING FLUID IN REDUCING TEMPERATURE ON MILD STEEL MACHINING OPERATION

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Abstract
The demand for biodegradable materials has created avenue for using vegetable oils such as neem seed oil, castor oil and water melon seed oil as alternative to conventional cutting fluids. This study determined the effects of neem oil as base in cutting fluid for machining operation. Two specific objectives guided the study, two corresponding research questions were posed and two null hypotheses formulated. Some aspects of the turning process on mild steel using High Speed Steel (HSS) cutting tool at varied spindle speed, feed rate and constant length of cut were observed using neem seed oil, soluble oil and straight oil in comparison. The research questions were answered using the mean while analysis of variance (ANOVA) was used to test the null hypotheses at $\alpha = 0.05$ significance level. The findings revealed that neem oil has lower temperature mean reading compared to soluble oil, and straight oil during turning operation of mild steel using HSS cutting tool at different feed rates and spindle speed, where the difference in mean temperature readings was significant. It was therefore recommended that machinists should use neem oil which is biodegradable and non-toxic as cutting fluid for machining, since it is environmentally and operator friendly.

Keywords: Neem oil, Cutting fluid, Mild steel, Machining operation

Introduction

Machining is a process by which a piece of metal is cut into desired shape, size, and surface finish by a controlled material-removal process using milling, lathes, and other cutting machines. Machining is normally the last stage in mechanical production which involves the removal of material chips in order to achieve the desired shape and size of the finished product (Ojolo & Ohunakin, 2011). Machining is mostly used in production technique to remove chips from less resistant material called work piece with the help of cutting tool in the machining process. The material cutting process results in removal of tiny parts or layers called chips. The chips accumulate on the tool face as they leave the work piece. As a result of this process, high normal and shear stress can be generated on the face of the tool which may cause undesirable effects in machining operation. This often causes heat generation in machining operation which affects the machinability. Nowadays, the machining industries are paying attention in improving product quality and productivity at greater cutting velocity and feed rate. It becomes extremely tough to attain both greater cutting velocity and feed rate because they cause very high cutting temperature. As a result of the high cutting temperature, premature failure of the cutting tools occurs in the cutting zone. The premature failure of cutting tool causes poor dimensional accuracy. It also degrades the surface integrity of the product by inducing tensile residual stresses and surface and sub-surface micro cracks.

Machining is accomplished through a combined action of cutting force and normal force and since there is no movement in the normal direction, the entire power is devoured by the cutting force to overcome frictions and to break down metal bonds (Ojolo & Ohunakin, 2011). The work piece thus suffers plastic deformation in the shear zone during metal cutting, and it is removed from the region as chips. The energy required for the deformation is converted into heat which is usually dissipated away through the work piece, cutting tool, and the chips. Heat generated in the process thus becomes the main problems in machining; with resultant effect as tool wear, uneven surface finish, and low quality of products. Consequently, Chang, Burke and Scenini (2018) observed that surface defects that result from machining can directly lead to the absorption of aggressive ions and can act as pre-cursors to crack nucleation. Therefore, reducing friction with lubricants, results in a reduction of the heat generated during machining. Lubrication, does not only increase shear angle but also reduces heat, and improve machinability. Hence, reduction of friction as well as the removal of heat from the chip-tool-work piece interface prolongs the service life of cutting tools. Ojolo and Ohunakin (2011) posit that cutting fluids are the lubricants in machining which can be straight oils, water miscible fluids, gasses and paste or solid lubricants.

Cutting fluids, as a component of machining industry, has been introduced and applied for over 100 years. It is believed that William Henry Northcott is probably the first man to mention the improvement in productivity that can be achieved when cutting fluid is applied in machining process (Adekunle, Odusot & Rabiu, 2012). This observation is published in his book "A Treatise on Lathes and Turning" in 1868. In 1907, Frederick Winslow Taylor pointed out that applying a heavy water stream on the tool/work piece interface, increased the cutting speed significantly by 30% - 40% (Adekunle, *et al.* 2012). Since then, the technology of cutting fluids has developed rapidly. Cutting fluids are essential in most metal cutting operations for reducing heat and friction created by the plastic deformation of metal occurring in the shear zone, when the chip slides along the chip-tool interface. This chip sliding action and frictional effect causes metal to adhere to the tools cutting edge, causing the tool to breakdown, resulting to inaccurate and poor surface finish of the work piece (Ksar & Oswald, 1990). Cutting fluids are designed to fulfill one or more of the following conditions: to cool the tool cutting edge and the work piece interface, thereby increasing the resistance of the mating portion to wear, to lubricate the chip and tool edge interface and reduce tool resistance to frictional and abrasion effect, to lubricate area of contact between the work piece and the tool edge, the tool rake face and the chip. In a situation where the use of expensive form of tools became necessary, application of cutting fluids is essential in order to reduce tool wear rate, reduce chances of formation of built up edge, improve surface finish of the machined surface and facilitates flushing of chips away from the cutting zone, thereby making the cutting zone more accessible to cutting tool edge (Lissaman & Martin, 1996).

The use of cutting fluids repeatedly over the time induces chemical changes of cutting fluids. These changes are due to the environmental effects, contamination from metal chips and tramp oil. The growth of bacteria and yeast becomes environmental hazard and also adversely affects the effectiveness of the cutting fluids. Cutting fluids degrade in quality with use and time and when they lose their quality the disposal of them is mandatory. Waste disposal of cutting fluids are expensive and affect the environment negatively (Carlson, 2006). The use of conventional cutting fluid in machining has been the general practice among manufacturing industries for reducing friction, heat and cutting power (Agrawal & Patil, 2018). In fact, the type and quality of cutting fluid used during machining plays a significant role in enhancing machinability if properly selected, used, handled, and disposed carefully. Therefore, selecting the right cutting fluid is as important as choosing the suitable machine tools, speed and feed. In other words the right cutting fluids always affect the output parameters. In addition, the ability of the cutting fluid to penetrate into the cutting zone is a critical issue; otherwise, the function of cutting fluid becomes useless. The use of cutting fluid permits higher cutting speeds, higher feed rates, greater depths of cut, lengthens tool life, decreased surface roughness, increases dimensional accuracy, and reduces power consumption (Abou-El-Hossein, 2008).

Over the ages, straight oils, water miscible fluids, gasses and paste or solid lubricants were used as cutting fluids. However, due to the increasing cost of petroleum products, manufacturers clamour for some bio-lubricants as substitutes for oil. Supportably, Nizamuddin, Agrawal and Patil (2018) asserted that almost 85% of the cutting fluids being used globally are derived from mineral oils, whose excessive use poses danger to the environment and health-related diseases. This therefore, accelerates the development of water-based fluids with different chemical compositions, performing different machining tasks. The introduction of mineral, vegetable and animal oil plays important role in enhancing various aspects of machining properties, including corrosion protection, antibacterial protection, lubricity, chemical stability and even emulsibility. This effort also stimulates the need to explore the use of neem oil as fluid for machining.

The neem tree (*Azadirachta indica Juss*) is a native to tropical and semi-tropical regions with origin in Europe and later domesticated in Asia. It is extensively found in India and Indonesia (Yakubu & Bello, 2015). It is also generally found in Northern Nigeria, and fairly found in Western Nigeria, where it is popularly referred to as *Dogon Yaro*. It is a tree in the mahogany family with broad dark stem and widely spread branches. It grows above 20m and produces evergreen leaves with white fragrant flowers and fruits. It is also drought resistant. All parts of the neem tree (the leaves, twigs and the nuts) where oil is extracted from, are used both industrially and for medicinal purpose. Neem oil is generally characterized with light to dark brown color, bitter and has a rather strong odor that is said to combine the odors of peanut and garlic (Rajeev, 2009).

Remarkable studies have been carried out to ascertain the lubricating and cooling capacity of various cutting fluids. Sokovic and Mijanovic (2001) understudied the ecological aspect of the cutting fluids and its influence on quantifiable parameters of the cutting processes. The result proved that water is best for cooling but a very poor lubricant while oil has great lubricating tendencies but poor cooling ability. Similarly, Ojolo and Ohanakin (2011) carried out study of rake face action on cutting using palm-kernel oil as lubricant. The work specifically investigated the effect of cutting speed, feed rate, depth of cut, and rake angle on main cutting force during the cylindrical turning of mild steel, brass, and aluminum rod, using high speed steel cutting tool and palm-kernel oil as cutting fluid. In the final analysis, the study established that palm-kernel oil (vegetable oil-based) has a good metal cutting lubricating capacity, performs better than mineral oil in lubricity, has high flash point with high natural viscosity, extending tool life, improving surface finish and dimensional tolerances with comfortable margins and does not contribute to health hazards via toxic mist and skin cancer in the work environment; it is also bio-degradable but its ability to function depends on the work piece being handled.

In the same vein, Agrawal and Patil (2018) carried out an experimental study of non-edible vegetable oil as a cutting fluid in machining of Molybdenum High Speed Steel (M2) using Minimum Quantity Lubricant (MQL). Having aimed at evaluating the performance of aloe vera oil as a cutting fluid in machining of M2 steel, carbide cutting tool insert was used as a cutting tool under different machining parameters with different types of cutting fluids such as aloe vera oil and conventional cutting fluid in machining. The result showed that aloe vera gives better surface finish compared to mineral oil, and also improved performance in terms of tool wear were found while comparing aloe vera oil with conventional cutting fluid.

Similarly, Nizamuddin, *et al*. (2018) examined the effect of karanja based soluble cutting fluid on chips formation in orthogonal fluid cutting process of American Iron and Steel Institute 1045 Steel (AISI 1045 steel). The study tried to compare karanja based cutting fluid prepared by using karanja oil (non-edible vegetable oil) with (Tween 80 emulsifier mixed in water) with conventional cutting fluid (Servocut S). The finding indicates that karanja based cutting fluid is reliable in reducing 11% chips thickness which significantly increases tool wear, surface roughness, and heat reduction during orthogonal cutting of AISI 1045 steel. Adekunle, Odusote and Rabiu (2012) also understudied the effect of using vegetable oils as quenching media for pure commercial aluminium. The study specifically determined the effects of rate of heat extraction by groundnut, melon, palm kernel, shea butter and palm oils on the mechanical properties of various samples of pure commercial aluminium heat treated at 200°C, 250°C, 300°C and 350°C respectively. The heat treatment was carried out by means of muffle furnace equipped with digital thermometer thermocouple. Tensile strength and hardness tests were done via Instron Universal Tester and Vickers hardness methods, respectively. The results obtained showed that palm kernel oil offer faster cooling at 200°C and 250°C, while palm oil and shea butter oil quench faster at 300°C and 350°C, respectively. Palm kernel oil proffers the highest elongation at 200°C, while at 350°C shea butter oil gave the outstanding result. The shea butter oil is best in providing good ductility at 200°C, while groundnut oil give the best result at 300°C and 350°C among the bio-quenching oils. Highest values of hardness were acquired from samples quenched in melon oil between 200°C - 300°C. Probably due to density and viscosity variation with temperature rise, these values however decreased with increased heating temperature. Observations made on most of other samples quenched in other bio-quenching oils used in the experiment shows that the locally available vegetable oils promises higher potentials to serve as substitutes for non-biodegradable mineral oils in many mechanical operations.

From the available literature so far, no study has tried experimenting the neem oil as cutting fluid for machining operation in comparison to other cutting fluids. Therefore, the need to determine the effects of neem oil as cutting fluid in reducing temperature on mild steel machining operation suffices.

Statement of the Problem

Accumulated heat during machining causes the temperature of the tool and the work contact zone to rise at fast rate which directly affects the surface finish of the product. The resulting high temperature induces metallurgical transformation such as softening of the work piece. The transformation leads to structural break down in the work piece and the tool material adversely affect the quality of the machined products in terms of dimensional accuracy and surface finish (Swarup & Kumar, 2011).

Cutting fluid have long been used in machining process to decrease the temperature during machining by spraying the coolant into machining zone directly on the cutting tool and the work piece (Safian, Noordin, Mohammed, Zainal, Izman & Adnan 2009). This has the effect of decreasing the tool temperature, enhancing surface finish of the work piece, and increases tool service life. However, the cutting fluids being used now are environmentally unfriendly, costly and potentially toxic. The recent shift to dry cutting has not completely solved the problem either. Dry cutting rather increases energy cost and requires a capital investment that is too large for most machine shops. To this end, the advantages of using cutting fluid have been questioned lately, due to several negative effects; Cutting fluid can cause skin and lung disease to the operator and air pollution to nature as well as cost of the fluid influence the amount of total machining cost. Elimination of using cutting fluid or dry machining can cause tool wear problems and poor surface finish. Hence, there is a need to source for an alternative local content bio-lubricant that is operator friendly. Therefore, this study sought to find out the effects of using neem oil as base in cutting fluid for temperature reduction during machining operation.

Aims and Objectives

The main aim of the study was to determine the effects of using neem oil as cutting fluid for machining operations in order to reduce temperature. Specifically, the study sought to:

(i) Determine the effect of neem oil on temperature when used as cutting fluid during machining processes (turning).

(ii) Determine the effect of neem oil, soluble oil and straight oil on temperature at different spindle speed.

Research Questions

The following questions guided the study:

(i) What is the effect of neem oil on temperature when used as cutting fluid during machining process (turning)?

(ii) What is the effect of neem oil, oil, soluble oil and straight oil on temperature at different spindle speed?

Hypotheses

The following null hypotheses were tested at 0.05 level of significance:

Ho_1: there is no significant difference in the mean temperature readings of neem oil, soluble oil, and straight oil when used as cutting fluid on mild steel work piece during machining operation.

Ho_2: there is no significant difference in the mean temperature readings of neem oil, soluble oil and straight oil as cutting fluid on mild steel work piece during machining process at different spindle speed.

Materials and Methods

The materials used for this study include:

(i) Lathe machine – Model: Harrison, Serial No. M300, 5.3 amps, 2.2kw, 380 volts, 50Hz.

(ii) Cutting tool –facing tool High Speed Steel (HSS) with 10° rake angle, 9° clearance angle, 1.5mm nose radius with 10mm tool overhang.

(iii) Thermometer of type 1202146, manufactured by Electronic Temperature Instruments Ltd, UK.

(iv) Micro-meter screw gauge

(v) Mild steel work pieces with diameter 49.50mm

The effects of neem seed oil, soluble oil, and straight oil on surface temperature of the work piece at varying spindle speeds, depths of cut and feed rates on the turning of mild steel were carried out on a Harrison lathe machine using a high speed steel (HSS) cutting tool. The experiments were carried out with the following specific procedures using the neem seed oil, soluble oil and straight oil as the cutting fluid.

(i) Turning operations of mild steel at varying spindle speeds (58, 85, 125, 180, 260 and 540 rev/min) and at variety of feed rate (1.0, 0.8, 0.6, 0.4, 0.2 mm/rev) and constant depth of cut of 6mm

(ii) Turning operations of mild steel at varying feed rates (1.0, 0.8, 0.6, 0.4, 0.2 mm/rev) and variety of spindle speed (58, 85, 125, 180, 260 and 540 rev/min) and constant depth of cut of 6mm.

(iii) Procedures 1, 2 and 3 were repeated using neem oil, soluble oil and straight oil as cutting fluid.

Immediately (5 seconds) after the turning operation the surface temperature was measured using the thermocouple thermometer, the temperature value is read off a digital display.

Results and Analysis

The results of the study are presented in tabular and chart form based on the research questions that guided the study.

Research Question 1: What is the effect of neem oil on temperature reduction when used as cutting fluid during machining process (turning)?

Table 1: Temperatures in Degree Celsius (°C) Obtained during Turning Operation under Variety Feed Rate and Spindle Speed with 100% Neem Oil, Soluble Oil and Straight Oil as Cutting Fluid

S/No.	Cutting fluids	Mean readings (°C)
1.	Neem oil	36.37
2.	Soluble oil	38.30
3.	Straight oil	41.59

The ambient environmental Temperature during the machining period was 34 °C.
Spindle speed = 180 rpm/min.
Length of cut = 9 mm.
Feed rates = 0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm, 1.0 mm.
Time: 5 seconds

Table 1 shows the effect of neem oil as cutting fluid in terms of temperature reduction at different feed rate. It is seen from Table 1 that neem oil as base cutting fluid has lower temperature mean readings than soluble oil and straight oil during turning operation. In case of straight oil as cutting fluid, the nature of variation in the mean temperature readings is highest among the other cutting fluids and for neem oil base cutting fluids the mean temperature generation is 36.37°C while soluble oil cutting fluid has 38.30°C and straight oil cutting fluid has the highest mean temperature readings of about 41.59°C. Therefore, neem oil as base cutting fluid possesses high effects in temperature reduction.

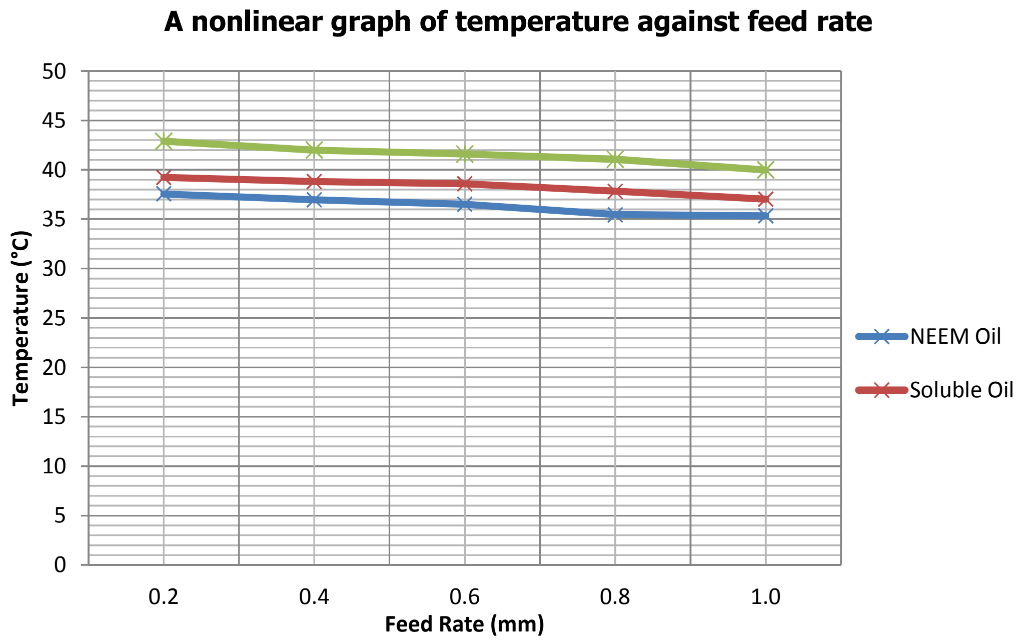


Figure 1: Variations of Temperature with Neem oil, Soluble oil, and Straight oil as Cutting fluid under different Feed rates.

In line with research question one, Figure 1 shows that neem oil is more effective in temperature reduction than soluble oil and straight oil at different feed rates and spindle speed and constant length of cut. Therefore, in line with Table 1 and Figure 1, neem oil was found to be the best cutting fluid in reducing temperature on mild steel during turning operations at different feed rate.

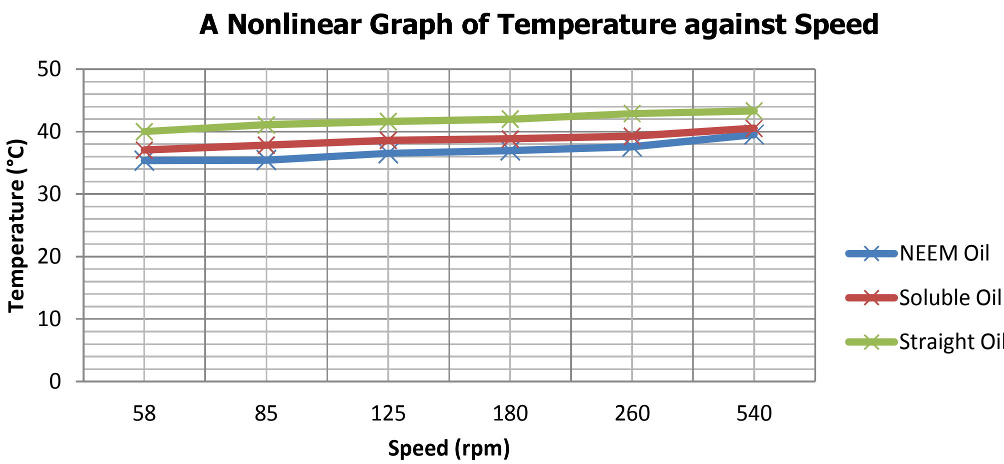
Research Question 2: What is the effect of neem oil, oil, soluble oil and straight oil on temperature at different spindle speed?

Table 2: Temperatures in Degree Celsius (°C) Obtained during Turning Operation under Variety of Spindle Speed with 100% Neem Oil, Soluble Oil and Straight Oil as Cutting fluid

S/No.	Cutting fluids	Mean readings (mm)
1.	Neem oil	36.89
2.	Soluble oil	38.67
3.	Straight oil	41.86

Ambient temperature: 34°C
Length of cut: 9.00 mm
Feed rate: 1.00 mm, 0.80mm, 0.60mm, 0.40mm, 0.20mm.
Time: 5 seconds

Table 2 shows that there is a difference in temperature reduction at variety of spindle speed as compared to the feed rate, the effect of neem oil as cutting fluid in terms of temperature reduction at different spindle speeds, indicates that neem oil as base cutting fluid has lower temperature mean readings than soluble oil and straight oil during turning operations. The nature of variation in the mean temperature readings is highest in straight oil followed by soluble oil and for neem oil base cutting fluids the mean temperature generation was 36.89°C while soluble oil cutting fluid was 38.67°C and straight oil cutting fluid had the highest mean temperature readings of 41.86°C. Therefore, neem oil as base cutting fluid under different spindle speed possesses high effects in terms of temperature reduction amongst the soluble oil and straight oil form the results obtained from the experiments. Figure 2 also shows the difference in temperature readings when neem oil, soluble oil and straight oil were used as cutting fluid under different spindle speed. Therefore, Table 2 and Figure 2 revealed that neem oil reduces temperature to great extent when used as cutting fluid than soluble oil and straight oil.



Hypothesis 1: There is no significant difference in the mean temperature readings of neem oil, soluble oil, and straight oil when used as cutting fluid on mild steel work piece during machining operation.

Table 3: Analysis of variance (ANOVA) of different cutting fluids in terms temperature reduction under variety of feed rate during turning operation

Source of variation	SS	df	MS	F cal.	F crit.	Remark
Between groups	69.71	2	34.86	36.01	3.89	Rejected
Within groups	11.62	12	0.967			
Total	81.33	14				

Table 3 shows that significant difference exist between the three cutting fluids: neem oil, soluble oil and straight oil when used as cutting fluid in operation of mild steel work piece. This is evident from the Table since f- calculated value was 36.01 which is greater than f-critical value of 3.89 at 0.05 level of significance. Therefore, the null hypothesis was rejected because the difference is significant. From Table 3 it was found that neem oil has influence in temperature reduction than soluble oil and straight oil when used as cutting fluid in machining operation at variety of feed rate.

Hypothesis 2: There is no significant difference in the mean temperature readings of neem oil, soluble oil and straight oil as cutting fluid on mild steel work piece during machining process at different spindle speed.

Table 4: Analysis of variance (ANOVA) of different cutting fluids in terms temperature at different spindle speed during turning operation

Source of variation	SS	df	MS	F cal.	F crit.	Remark
Between groups	75.97	2	37.98	21.72	3.68	Rejected
Within groups	26.23	15	1.75			
Total	102.19	17				

Table 4 shows that there is significant difference in the mean temperature readings of neem oil, soluble oil and straight oil as cutting fluids in turning operation of mild steel work piece using HSS cutting tool during teaching machining operation. This is evident from the table since calculated f-value of 21.72 which was greater than f-critical value of 3.68 at 0.05 level of significance. Therefore, the null hypothesis was rejected. It implies therefore that neem oil has significant effect on temperature reduction than soluble oil and straight oil when used at cutting fluid in machining operation at different spindle speed.

Findings of the Study

The following findings were made from the study:

(i) Neem oil as base cutting fluid has lower temperature mean reading based on reading obtain during turning operation of mild steel work piece using HSS cutting tool at different feed rates and spindle speed.

(ii) There was significant difference in the mean temperature readings of neem oil, soluble oil, and straight oil as cutting fluid in reducing temperature on mild steel work piece during machining operation (turning) using high speed steel cutting tool at different feed rates and spindle speeds.

Discussion

The findings related to research questions indicate that neem oil as base cutting fluid reduces temperature to a great extent than soluble oil and straight oil during turning of mild steel work piece using HSS cutting tool at different feed rate during machining operation. This finding is consistent with Agrawal and Patil (2018); Ojolo and Ohunakin (2011) whose studies found that vegetable oils (neem oil, aloe vera, and Palm Kernel oil) give better performance in reducing temperature during turning operation. The finding is further congruent with Nizamuddin, *et al.* (2018), whose study confirmed that karanja based cutting fluid (non-edible vegetable oil) is reliable in reducing 11% chips thickness which significantly increases tool wear, surface roughness, and heat reduction during orthogonal cutting of AISI 1045 steel. Similarly, the finding conforms to Swarup and Kumar (2011) whose study on the surface quality during high speed machining using eco-friendly cutting fluid found that, neem seed oil aided the flow of chips throughout the turning process, hence producing high surface finish and constant chips which are characteristics of good machining lubricant.

Furthermore, the finding agrees with Ojolo and Ohunakin (2011) whose study established that palm-kernel oil (vegetable oil-based) has a good metal cutting lubricating capacity, performs better than mineral oil in lubricity, has high flash point with high natural viscosity, extending tool life, improving surface finish and dimensional tolerances with comfortable margins and does not contribute to health hazards via toxic mist and skin cancer in the work environment; it is also bio-degradable but its ability to function depends on the work piece being handled. Finally, the finding is compatible with Adekunle, *et al.* (2012) whose study on the effect of using vegetable oils as quenching media for pure commercial aluminum attests that locally available vegetable oils promises higher potentials to serve as substitutes for non-biodegradable mineral oils in many mechanical operations.

The analysis of data relating to the two null hypotheses reveals that there was a significant difference in the mean temperature readings of neem oil, soluble oil, and straight oil as cutting fluid in reducing temperature on mild steel work piece during machining operation (turning) using high speed steel cutting tool at variety of feed rate, and spindle speed. This agrees with the results of Adekunle, *et al.* (2012); Agrawal*, et al.* (2018); Nizamuddin, *et al.* (2018); Ojolo and Ohunakin (2011); and Swarup and Kumar (2011) asserted that there exists a significant reduction in temperature when neem oil is used as cutting fluid during work piece machining operation.

Conclusion and Recommendations

The major findings of this study serves as the basis for drawing conclusion that temperature reduction was best obtained using neem oil as base cutting fluid than soluble oil and straight oil. The significant contribution of neem oil in machining of mild steel work piece using HSS cutting tool offered the reduction of temperature of mild steel during turning operation at different spindle speed and variety of feed rate. Based on the experimental result, the following recommendations were made:

(i) The mechanical technology teachers should recommend the use of neem oil as an alternative cutting fluid for application on various machining and project produced in the school workshops.

(ii) Mechanical technology teachers should encourage students to use neem oil as cutting fluid or preservatives on their various machining operation and course practical projects.

(iii) The Federal Ministry of Labour and Employment should encourage industries and entrepreneurs to venture into the new area of investment in the production and marketing of neem oil with assurance of sustainable renewable source of raw materials.

(iv) The Federal Ministry of Labour and Employment should encourage the society at large should be encouraged to plant neem trees there by exploring the economic benefit and new market for the seeds and the oil having established the non-toxic nature of neem oil as a substitute for other cutting fluids which are more expensive and toxic.

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