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FORMULATION AND PERFORMANCE ASSESSMENT OF FIXED OILS BASED CUTTING FLUIDS IN MACHINING OPERATION

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ABSTRACT

This research –formulation and performance assessment of fixed oils based cutting fluids in machining operation was done to examine the performance of cutting fluids developed from Shea butter and Neem seed oils (fixed oils) in the straight turning of AISI 1027 steel bar using high-speed steel (HSS) tool. The performance and characteristics of the cutting fluids developed were compared with mineral oil-based cutting fluid- USA metal cutting oil CA2000 (Model 2317 4200^N) as the control sample. Generally, mineral oils are costly, not environmentally friendly and so pose a serious problem of disposal since they are not biodegradable. The turning was done at different spindle speeds (530rpm, 750rpm, 1060rpm) and depth of cuts (1.0mm, 1.5mm, 2.0mm) at a constant feed rate of 0.25mm/rev for the mineral oil, formulated cutting fluids and dry turning operation. Each experiment was observed for at least 10mimutes and the cutting oils were fed automatically at the tool-work interface. A thermocouple was used to record the temperature of the tool-work interface at every point. The result shows that a minimum temperature of 31.5^{o}C was obtained when turning at 530rpm/1.0mm and a maximum of 37^{o}C was obtained when turning at 1060rpm/2.0mm using Shea butter based cutting fluid. This shows that Shea butter based cutting fluid was far better than the control sample and Neem seed oil based cutting fluids in term of temperature dissipation. In term of acidic values, the minerals oil base cutting fluid contains more acid of 8.4g/dm^3 relative to the two fluids developed from the fixed oils. The viscosity of the developed cutting fluids is better at higher temperatures standing at values of 233.76/227.35cp and 205.83/141.80cp at 40^{o}C/80^{o}C and that of the control sample at 111.34/46cp at 40^{o}C/80^{o}C.

KEYWORDS: *Fixed Oils, Mineral Oil, Cutting Fluids, Turning, Steel, Spindle Speed and Depth of Cut*

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INTRODUCTION

The major problems being contended with in machining operations are the rate of heat dissipation, tool life, effects of cutting fluid on work piece and machine parts, dimensional accuracy of work, production rate and general environmental effects of cutting fluids.

During machining operations, heat is generated and this has adverse effects on workpiece surface finish and dimensional accuracy, tool wear, and life, as well as production rate. Lubricants are therefore employed in machining operations to either achieve cooling, cooling, and lubrication, lubricate mainly, or minimize chip adhesion to workpiece or tool; and the goal of employing a lubricant in any machining operation is dependent on choice from among the listed functions (Chernor, 1972). Whichever function a cutting fluid is to serve in any machining operation, it must possess some qualities, which have been identified (Sharma, 2005) as high decomposition or oxidation temperature, must not be gummy, should not foam or smoke unduly, must not be a contaminant to lubricants used elsewhere in the machine. If these qualities are lacking, the cutting fluid may result in serious ecological or health issues (Kalhofer. 1997). It has been observed that expenses on cutting fluids form major parts of manufacturing costs per part produced. It is ,therefore, a cost-cutting measure to develop costeffective and efficient cutting fluids for machining processes (Ibhadode.2001)

Mineral or fossil oil-based cutting fluids are generally costly and not environmentally friendly. They pose a very serious problem of disposal since they are not bio-degradable. Mineral oil based cutting fluids are known to be irritating to the skin of operators (cause dermatitis) (Lawal et al, 2012) leading to rashes and other forms of discomforts. Fumes from mineral oil-based cutting fluids cause some respiratory problems which may be mild or severe (e.g. bronchitis). Health and Safety Executive (HSE) report indicated that about 80% of all occupational diseases of operators were due to skin contact with metalworking fluids (Lawal et al, 2012). Conscious of the above problems, an effort is being made in this piece of work to produce cutting fluids from bio-resources that can perform satisfactorily and as well address these unwanted situations.

Negative factors of fossil oilbased cutting fluids have combined to propel the need for the prompt investigation into the use of biodegradable coolants and lubricants. Researches into the possibility of replacing petroleum-based metal-working fluids with those based on vegetable oils have become intense in recent years (Paul et-al, 2011).

Fixed oils are the natural vegetable or animal oils which are non-volatile e.g. lard oils, linseed oil, etc. They do not evaporate at room temperature and can easily be sponified.

Cutting lubricants may consist of pure oil, a mixture of two or more oils or a mixture of oil and water (Akpobi and Enabulele, 2002). Oils are generally divided into two groups: the fixed oils and the mineral oils. The fixed oils have greater “oiliness” than the mineral oils, but they are not so stable and tend to become gummy and decompose when heated. In this group are the animal and vegetable oils. On the other hand, the mineral oils group is obtained from crude petroleum mined from the oil fields. The most common type of lubricant used for cutting is soluble oil, which when mixed with water, forms a white solution known as “suds” or “slurry”. This has better cooling properties than oil but does not lubricate as much. The oil part of it is generally a mineral oil mixed with a soap solution (Chapman, 1972).

MATERIALS AND METHODS

Materials

The following materials were used in the course of the experiment:

- Workpiece
- Mineral oil
- Fixed oils (Shea butter and Neem seed oils)
- Phenol was used as a disinfectant.
- Sulphur was used as an extreme pressure agent.
- Washing Soda was used as the emulsifier.

- Water was used as a solvent

Work Piece

Workpiece used was mild steel bar of 50mm diameter and 150mm length. The chemical composition of the work-piece is shown in Table 1

Table 1: Chemical Composition of the Work Piece (Source)

Mat.	C	Si	Mn	P	S	Fe
mild steel	0.265	_	0.060	0.001	_	Bal.

Mineral Oil

Mineral oil-based cutting fluid (USA Metal cutting oil CA 2000; Model 2317 4200^{N}) was used as the control sample.

Fixed Oils

Shea Butter Oil

Shea oil is a vegetable oil obtained from the seeds of a tree commonly known as the Shea tree (Vitellariaparadoxa) which is a tree of the Sapotaceae family (World Agroforestry center). It is an African indigenous tree. It grows naturally in the wild in the dry Savannah belt of West Africa.

The Shea fruit consists of a thin, tart nutritious pulp that surrounds a relatively large, oil-rich seed from which the Shea nut oil is extracted.

A test found at the site of the medieval village of Saouga is evidence of Shea butter production by the 14^{th} century (Neuman et – al, 1998).

Shea butter has many uses whether refined or not. It is mostly used as emollient in the cosmetics industry in the West, while its extensive use as food is in Africa where it is a source of dietary fat and for medicinal purposes.

The properties of vegetable oils which enhance their performance in machining operations include the presence of fatty acids, surface active ingredients such as stearic acid and halogens such as Chlorine which help to reduce surface energy and improve its wetting power or oiliness (Obi et – al, 2013).

Obi et al (2013), found out that at a depth of 3.0mm the surface temperature using Shea oil in the turning of Aluminum was 49.1^{o}C, 2.5mm was 46.8^{o}C, 2.0mm was 43.9^{o}C, 1.5mm was 41.2^{o}C and 1.0mm was 38.5^{o}C. It has been shown that the coefficient of friction reduces as cutting speed increases when Shea butter is used as metalworking fluid. It was therefore, concluded that Shea butter is effective in reducing cutting force during cylindrical machining due to the enhanced lubricating ability of the oils on account of their high molecular weights (Ojolo, et-al, 2008).

Neem Seed Oil

Neem seed oil is a vegetable oil pressed from the fruits and seeds of the Neem tree (AzadirachtaIndica), also known as Indian Lilac, an evergreen tropical tree. Neem oil is the most important of the commercially available products of neem for organic farming and medicine. It is hydrophobic in nature, so in order to emulsify it in water for application purposes, it must be formulated with appropriate surfactants.

In evaluating the performance of neem seed oil as a cutting fluid in orthogonal machining of Aluminium alloy (Al-Mn) in turning operation, Yakubu, et-al (2015) obtained that the neem oil reduced surface roughness by 39% and 22% when compared to soluble oil and dry machining respectively. It was established from the result that the neem oil gave the lowest flank wear at the spindle speed of 250 r.p.m., feed rate of 1.05mm/rev and depth of cut of 0.5mm as compared to dry and soluble oil machining. The neem seed oil conclusively reduced the flank wear by about 72% and 56% as compared to dry turning and soluble oil turning respectively, while the soluble oil reduced the flank wear by 32% as compared to dry turning. Monsur, et-al (2015) while evaluating the performance of different cutting fluids in the machining of Aluminium-Manganese alloy in turning operation concluded that minimum surface roughness and best surface quality was obtained using neem seed oil as cutting fluid as compared to soluble oil cutting fluid in machining operations. It was the most effective in reducing surface roughness as spindle speed increased. Neem seed oil generated the highest reduction in flank wear when machining Al-Mn alloy at a spindle speed of 200 r.p.m., a feed rate of 0.5mm/rev and depth of cut of 1.0mm.Erakhrumen, (2011) in his work gave some physicochemical properties of neem oil, thus: Specific gravity of 0.91 ± 0.01: the Acid value of 18.24 ± 1.31 $mgKOH.g^{-1}$: Saponification value of 172.88 ±2.06: Colour – dark brown, Liquid at room temperature

Equipment

- E3N-01 Centre Lathe.
- The cutting tool used was a single point High-Speed Steel (HSS).
- Thermocouple for direct measurement of temperature at the tool-work interface.
- Timer (stop clock).
- Graduated measuring cylinder.
- Vernier calipers.

Experimental Design

For this research, a factorial design was adopted with three levels and two factors expressed as:

$L^f \times n$

Where; f = number of factors

L = number of levels

n = Number of replication

$3^2 \times 2 = 18 \times 4 = 72$

This then means that for every cutting fluid, eighteen experiments will be run with a total of seventy-two runs (72) for the entire cutting fluids including dry cutting. Table 2 shows machining parameters and levels

Table 2: Machining Parameters and Levels (Source)

Level	Spindle Speed (rpm)	Depth of Cuts (mm)
1	530	1.0
2	750	1.5
3	1060	2.0

Methods

Formulation of Cutting Fluids from Fixed Oils

The cutting fluids were formulated by combining the three major components viz: Base oil, Emulsifier and Other additives, (i.e. Base oil + Emulsifier + Other additives).

***Base oil*:** The base oils used in this case are the Shea butter and Neem seed oil (specimens B, and C).

***Emulsifier*:** The function of the emulsifier is to disperse the oil in water. In this case, washing Soda was used.

***Additives*:** There are various additives that are being used in cutting fluids for various purposes. Here, additives used are extreme pressure agent and disinfectant. Sulphur is used as the extreme pressure agent due to its safety for the environment; it does not generate combustible gases or hazardous combustion residue during disposal. It also has excellent lubrication properties. Phenol, on the other hand ,was added to the formulation as a disinfectant.

Formulation Ratio

Formulation was done in the ratio 80:10:5:5 i.e. 80% fixed oil, 10% emulsifier, 5% extreme pressure agent and 5% disinfectant.

Mixing of the Cutting Fluids with Water

The formulated cutting fluids, as well as the reference sample, were mixed with water in the ratio 1:10 (i.e. 1 part of cutting fluid to 10 parts of water). All the formulations and mixing were done at room temperature.

Viscosities and Acidic Values

Viscosities

The viscosities of the cutting fluids were determined using Ostwald viscometer. The fluids will be made to flow via a capillary tube of the said viscometer between two marks on the viscometer. The time is taken for the fluid to flow from the upper mark to lower mark and the distance of travel are parameters for the viscosity determination. The quantitative value of the viscosity will be determined using Ostwald equation expressed as:

$$.v = mt\left(\frac{v_r}{m_r t_r}\right) \quad (2)$$

Where; v = Viscosity of fluids to be determined

m = Mass of fluids to be determined

t = Time taken by the fluid to flow down

v_r = Viscosity of reference fluid

m_r = Mass of reference fluid

t_r = Time taken by reference fluid to flow down

Acidic Values

The acidic value of all fluids with the control sample inclusive was determined by titration. 0.1M of NaOH was used as a base for the titration with about 5ml of each sample and phenolphthalein as an indicator.

Machining and Temperature Dissipation Abilities

This is meant to test the performance of the formulated cutting fluids. AISI 1027 Steel samples of lengths 250mm and cross-sectional areas of... were straight turned between center on E3N-01 lathe machine using High-speed steel (HSS) tools of the same tip configuration. Every experiment was run for at least ten (10) minutes. Cutting fluid was automatically supplied to dissipate the heat generated at the tool/work interface. The temperature at the tool/work interface was measured with the aid a digital thermocouple.

RESULTS AND DISCUSSIONS

Temperature Variations

Table 2: Temperature Variation for all Samples (Source...)

Sample	Level	Spindle Speed (rpm)	Depth of Cut (mm)	Av. Temp. (^{O}C)
A (Control Sample)	1	530	1.0	33.0
	2	750	1.0	33.0
	3	1060	1.0	34.0
	1	530	1.5	34.0
	2	750	1.5	35.0
	3	1060	1.5	36.0
	1	530	2.0	35.5
	2	750	2.0	36.5
	3	1060	2.0	38.
B (Shea butter Oil)	1	530	1.0	31.5
	2	750	1.0	32.5
	3	1060	1.0	33.0
	1	530	1.5	34.0
	2	750	1.5	34.0
	3	1060	1.5	35.0
	1	530	2.0	34.0
	2	750	2.0	36.0
	3	1060	2.0	37.0
C (Neem Oil)	1	530	1.0	35.0
	2	750	1.0	38.5
	3	1060	1.0	39.5
	1	530	1.5	38.5
	2	750	1.5	39.5
	3	1060	1.5	40.0
	1	530	2.0	38.5
	2	750	2.0	40.5
	3	1060	2.0	42.0
D (Dry Machining)	1	530	1.0	44.0
	2	750	1.0	46.0
	3	1060	1.0	50.0
	1	530	1.5	63.0
	2	750	1.5	66.0
	3	1060	1.5	75.0
	1	530	2.0	67.0
	2	750	2.0	70.0
	3	1060	2.0	84.0

The graphs of the variations of temperatures with spindle speeds are shown in figures 1, 2 and 3.

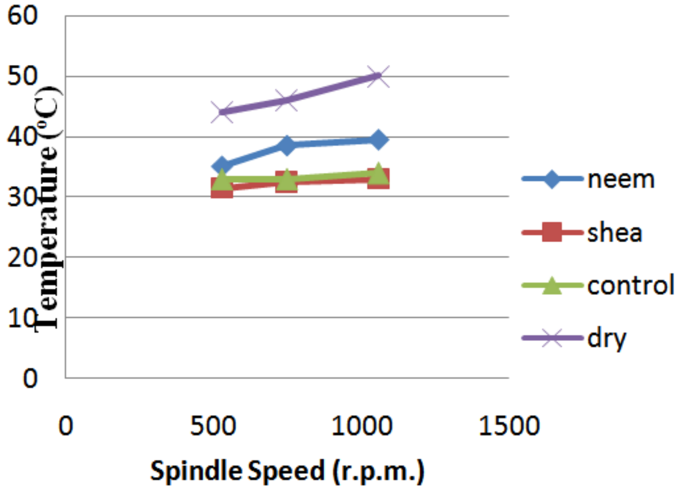

Figure 1: Temperature against Spindle Speed at a Depth of Cut of 10mm. (Source)

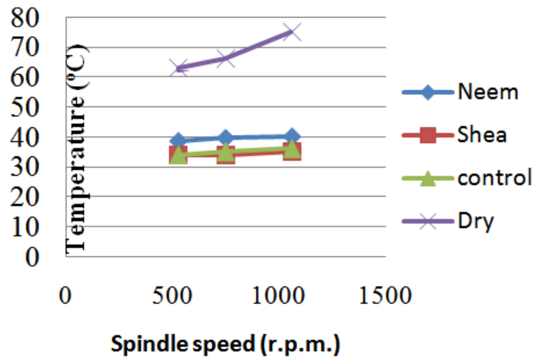

Figure 2: Temperature against Spindle Speed at a Depth of Cut of 1.5 mm

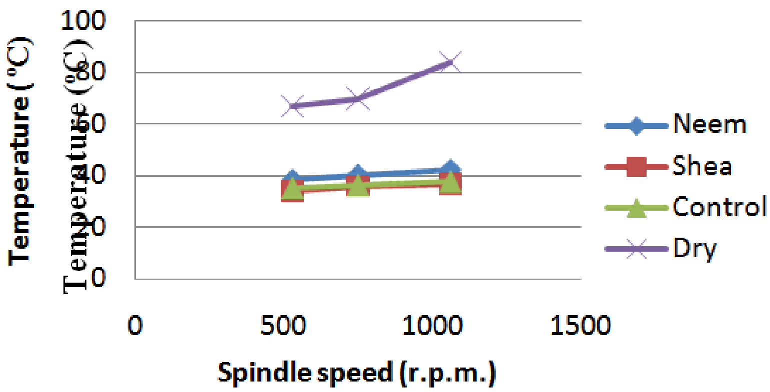

Figure 3: Temperature against Spindle Speed at a Depth of Cut of 2.0 mm

Viscosity

Table 3 shows the viscosities of all samples at 40°C and 80°C

Table 3: Viscosities of All Samples (Source...)

Sample	Viscosity at 40°C (cp)	Viscosity at 80°C (cp)
A	111.34	46.40
B	233.76	227.35
C	205.83	141.80

Acidic Values of Samples

Table 4 shows the acidic values of all samples.

Table 4: Acidic Values of all Samples (Source...)

Sample	Acidic Value (g/dm^3)
A	3.4
B	1.4
C	1.8

Findings

The following were found out or re-established in the course of this study:

- A depth of cut affects the temperature at the tool-work interface. Thus, the larger the depth of cut, the more the heat generated and the other way round.
- Increase in spindle speed increases the heat generated at the tool-work interface.
- Temperatures are extremely high during dry machining.
- Chips formed during dry machining were discontinuous and blue-black in color and the surface finish was poor.
- Chips formed using cutting fluids were continuous and grey in color.
- Chips formed using Shea butter based cutting fluid was outstandingly continuous as they formed endless or very long ribbons. In addition, the chips formed is very smooth relative to the chips produced using other cutting, in other words, the chips is friendly to touch.
- Neem seed oil based cutting fluid was found to perform best at low speeds and smaller depths of cut.
- Although it performed well in conducting heat away from the tool-work interface, the control sample was found to be inferior to the shea butter based cutting fluid. However, it was found to be better than Neem seed oil based cutting fluid.
- B and C have relatively low acidic values and therefore have the least tendency to corrode the metal.

DISCUSSION OF RESULTS

The graph of temperature against spindle speed at a depth of cut of 1.0mm (figure 4.1) and feed rate of 0.25mm/revolution shows how the temperature at the tool-workpiece interface varied as the spindle speeds were varied while applying different cutting fluids and during dry machining. The ambient temperature at the time of the experiment was 28ºC. The results clearly show that during dry machining, the temperature significantly increased with an increase in spindle speed. However, with the use of the cutting fluids, the increase in temperature was minimal, especially when Shea butter based cutting fluid was used. The Shea butter cutting fluid at this point proved to be more effective in conducting heat away than the rest. The deviation of its values from that of the control sample is on the positive side indicating better performance in conducting heat away from tool-workpiece interface at 1.0mm and the varied spindle speeds. The tool – work interface temperature reduces with a decrease in the depth of cut. This is inconsonant with the research carried out by Obi, 2013. The control sample nevertheless, performed better than the Neem seed oil based cutting fluid at the 1.0mm depth of cut and the varied spindle speeds. This agrees with the study by Ojolo et-al, 2008.

As the depth of cut was increased to 1.5mm (figure 4.2), Neem seed oil based cutting fluid and the control sample produced gradual increases in temperature as the spindle speeds were varied, while the Shea butter based cutting fluid maintained the same temperature (34ºC) for 530 r.p.m. and 750 r.p.m. after which it increased slightly at 1060 r.p.m. The graph (figure 4.2) shows how the Shea butter based cutting fluid tends to compete conveniently with the conventional cutting fluid. At a relatively low speed of 530 r.p.m., the tool-work interface temperature for the control sample and Shea oil were the same (34ºC), but as the spindle speed increased, the Shea butter based cutting fluid proved to have better capacity to conduct heat away which could be due to the presence of fatty acids which favor boundary lubrication and its viscosity at higher temperatures. Neem seed oil based cutting fluid, however, could be seen to give comparatively less performance at the given spindle speeds as the depth of cut was increased. This could suggest its suitability as a cutting fluid at smaller depths of cut and lower spindle speeds.

The graph of temperature against spindle speed at the 2.0mm depth of cut (figure 4.3) shows how the Shea butter based cutting fluid proved to have an edge over the other cutting fluid samples at higher depths of cut and higher spindle speeds. This indicates its suitability for heavy cuts at high spindle speeds. Shea butter based cutting fluid at this depth of cut performed better than the control sample. Among the three cutting fluids, Neem seed oil-based cutting fluid produced the highest tool-work interface temperature. However, when the temperature generated during dry machining (which is relatively very high) is taken into consideration, the effectiveness of the cutting fluids in conducting heat away from the work zone is more appreciated.

CONCLUSION AND RECOMMENDATIONS

Conclusion

From the foregoing, it can be concluded that fixed oils can be used in the production of cutting fluids for machining operations. Shea oil-based cutting fluid was found to be the best among the three cutting fluids in conducting heat away from tool-workpiece interface especially at larger depths of cut and higher spindle speeds. It was followed by the control sample (mineral oil based) and then the neem seed oil based. Fixed oils which have the advantage of being bio-degradable, less toxic, availability and cheapness coupled with their efficient performance in machining operations can conveniently substitute the conventional (mineral oil based) cutting fluids for all machining operations under various operational conditions.

Recommendations

With the knowledge of the fact that no research work can be considered conclusive in itself, the following are recommended:

- More efforts should be put into research in the use of bio-oils as cutting fluids since they have been proved to have good prospects.

- The cutting fluids formulated in this research work should be experimented in other machining processes, eg. Milling, drilling, etc.
- A research should be undertaken to ascertain the best compositional ratio of the base oil to the other additives for best performance in each of the bio-oils used in this work.
- A proactive measure should be taken to sensitize all metal workers on the effectiveness of bio-oils based cutting fluids so that, as they continue to use them more data can be generated about their efficiency in diverse areas; this may also boost the commercial production of the bio-oils based cutting fluids.

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