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Experimental Investigation of Lard and Tallow Oils Suitability in Turning Operation of Hypo-Eutectoid Steels

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Abstract Cooling and lubrication in machining are important in reducing the severity of the contact processes at the cutting tool-workpiece interface. Currently, there are wide scale evaluations of the use of metal working fluids (MWFs) in machining, so as to reduce the amount of lubricants in metal removing operations. The increasing awareness of the general public on the environment and health impact of mineral oil-based metal cutting fluids (MCFs) is forcing machine workshop operators to reduce their use as cutting fluids and in search for more environmental friendly animal oil-based cutting fluids. Based on this, commercially available animal oils are currently been exploited as potential oils for formulation of animal oil-based cutting fluids. It is therefore necessary to conduct machining trials to determine the suitability of these oils in metal cutting operations such as turning, drilling and milling etc. This study investigates the effect of the selected cutting fluids on certain machining parameters in turning operations of hypo-eutectoid steels using carbide cutting tool. The selected oils purchased from a local market in Ibadan, Nigeria were sieved to remove any foreign particles or dirt. The solution (water, additives, and base-oil) were mixed at an elevated temperature of 55^{o}C in a proportion 5:1:2.The essence of the emulsifier (additive) was to prevent separation of water from oil. The steel samples obtained from a steel company in Nigeria after spectrochemical analysis, were machined on a variable speed center lathe under different machining parameters. Experimental results clearly showed that Conventional cutting fluid might be replaced with Non-conventional one like LOCFs and TOCFs as they give better performances. With slight modifications and deliberate but careful alterations in some of the components of such oils, better performing cutting fluids could be obtained.

Keywords Hypo-eutectoid, Cutting fluids, Emulsifier, Machining Parameters, Evaluation

Introduction

Hypo-eutectoid steel is a plain carbon steel with less than 0.77 percent carbon. It consists of ferrite and pearlite at room temperature [1]. This steel has an excess of ferrite above that required to mix with the cementite present to form pearlite. Low-alloy steels like hypo-eutectoid steels are a group of steels with a very large application in engineering designs [2]. One of the ways in which hypo-eutectoid steel is processed to form the required need of man is machining.

Machining is the process of removing unwanted material from component in the form of chips to produce the desired shape [3]. In machining process, a tool penetrates into the work piece and removes the material in the form of chips which consume a major portion of energy. The greater the energy consumption, the greater are the temperature and frictional forces at the tool chip interface and consequently, the higher will be the tool wear [3-4]. Thus, the performance of the machining is based on the type of cutting fluid and the method of application [5].

The application of coolants in machining is undergoing revolution [6]. According to Rahman et al. (2012) cutting fluids are used in metal machining for a variety of reasons such as improving tool life, reducing work piece thermal deformation, improving surface finish and flushing away chips from the cutting zone [6]. 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.

Most of the machine working fluids (MWFs) are mineral oil-based fluids and these fluids increase productivity and the quality of manufacturing operations by cooling and lubricating during metal cutting and forming processes. Due to their advantages, the consumption of MWFs is increasing in machining industry [8].

However, the increasing awareness of the society and government to the environment and health impact of mineral oil-based metal cutting fluids (MCFs) is forcing machine workshop operators to reduce their use as cutting fluids and in search for more environmental friendly animal oil-based cutting fluids. In this quest, commercially available animal oils are currently been exploited as potential oils for formulation of animal oil-based cutting fluids. There is therefore the need to conduct machining trials to determine the suitability of these oils in metal cutting operations like turning of ferrous and non-ferrous metals.

Turning as a metal cutting process used for the generation of cylindrical surfaces is carried on a lathe. It provides the power to turn the work piece at a selected rotational speed, feed to the cutting tool at specified rate and depth of cut. Therefore three cutting parameters namely cutting speed, feed and depth of cut need to be determined in a turning operation. The turning operations are accomplished using a cutting tool with high hardness help to sustain the high cutting forces and temperature during machining create a harsh environment for the cutting tool. In addition tool life and surface roughness are other important parameters required in evaluating cutting performance in a turning operation [9]. However, this research is aimed at evaluating the performance suitability of lard and tallow based cutting fluids as potential cutting fluids in turning of hypo-eutectoid steels using carbide cutting tool steels. This was achieved via investigation of the effect of those selected fluids on certain parameters like tool temperature, tool life, spindle power consumption, Work-piece under roughness and chip formations etc., as compared to the conventional mineral oil-based MCFs.

Methodology

Five (5) pieces of hypo-eutectoid steel rods, High Speed Steel (HSS) tool, emulsifier, Lard Oil, Tallow Oil and Conventional Mineral Oil based cutting fluids were used in this research. The steel samples were obtained from Universal Steel Limited, Ogba, Ikeja-Lagos State, Nigeria. The results of the chemical compositions of those steel samples obtained via an optical electron spectrometer (OES) are presented in table 1.

Table 1: Spectrometric Analysis of Hypo-eutectoid Steel Sample

Element	**C**	**Si**	**Mn**	**S**	**P**	**Cr**	**Ni**	**Cu**
%Composition	0.2800	0.2070	0.6740	0.0310	0.0280	0.0710	0.0870	0.1370
Element	**Nb**	**Al**	**B**	**W**	**Mo**	**V**	**Ti**	**Fe**
%Composition	0.0001	0.0020	0.0001	0.0001	0.0001	0.0001	0.0170	98.4660

The equipment used for the experimental work include: centre lathe (variable speed), optical electron spectrometer (OES), digital thermocouple, stop watch, digital weighing balance, vibration meter (SD Card Data Logger-VB 8206SD), Magnifying glass (SANDVIK Coromant- Tool Wear), USB Data Logger and computer system. The selected oils shown in fig. 1 and emulsifiers were purchased from a local market (Ogunpa market) in Ibadan, Oyo State, Nigeria. These lard and tallow oils were sieved to remove any foreign particles or dirt. The solution were mixed in the proportion shown in Table 2. The emulsifier (0.5 M sodium lauryl sulphate + nitrosol + sodium tripolyphosphate + sulphonic acid + calcium carbonate) was added to prevent separation of water from oil. The mixing was carried out at an elevated temperature of 55°C as used by Sharafadeen and Jamiu (2013) [10].

Table 2: Constituents of Cutting Fluids

Cutting Fluids	% Water	% Additives	% Base Oil	Mixture Ratio	Total (%)
LOCFs	52.5 (105cl)	12.5 (25cl)	35 (70cl)	4:1:3	100
TOCFS	52.5	12.5	35	4:1:3	100
MCFs (As purchased)	100	-	-	-	100

(a) Lard Oil (b) Tallow Oil (c) Mineral Oil (MCF)

Figure 1: Cutting fluids

AISI 1028 steels, as the hypo-eutectoid steel samples used have a length of 85mm with ϕ16. The workpieces from the same batch were used in the experiments. The cutting tool used in form of tool tip was high speed steel tool (150 x 10 HSS). The turning experiments were carried out on a variable speed centre lathe (Model AMI-STUDENT-175-1000MM). Turning of the steel samples was done at an ambient environment of 28.5°C. Thus, the level of experimental parameters used for the machining is presented in table 3.

Table 3: Level of Experimental Parameters

Machining Parameters	Cutting speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)
Independent Variables	165	0.22	1.0
	110	0.44	2.0
	73	0.11	3.0

In addition, the table used in selecting both cutting speed and feed rate for the machining operation is presented in fig. 2.

A	835	1535	F
B	557	1025	A
C	371	683	S
D	247	455	T
A	165	303	S
B	110	202	L
C	73	135	O
D	48	90	W
LEVER	LOW	H	LEVER

LONGITUDINAL FEED

CY	0.67	0.75	0.83	0.9167	1	1.083	1.167
AY	0.44	0.5	0.56	0.6111	0.67	0.722	0.778
CX	0.33	0.375	0.42	0.4583	0.5	0.542	0.583
BY	0.27	0.3	0.33	0.3667	0.4	0.433	0.467
AX	0.22	0.25	0.28	0.3056	0.33	0.361	0.389
CZ	0.17	0.188	0.21	0.2292	0.25	0.271	0.292
BX	0.13	0.15	0.17	0.1833	0.2	0.217	[illegible]
AZ	0.11	0.125	0.14	0.1528	0.17	0.181	[illegible]
BZ	0.06	0.075	0.08	0.0917	0.1	0.108	[illegible]

TRANSVERSE FEED

CY	0.17	0.188	0.21	0.2292	0.25	[illegible]	[illegible]
AY	0.11	0.125	0.14	0.1528	[illegible]	[illegible]	[illegible]
CX	0.08	0.094	0.1	0.1146	[illegible]	[illegible]	[illegible]
BY	0.07	0.075	0.08	0.0917	0.1	[illegible]	[illegible]
AX	0.06	0.063	0.07	0.0764	[illegible]	[illegible]	[illegible]
CZ	0.04	0.047	0.05	0.0573	[illegible]	[illegible]	[illegible]
BX	0.03	0.038	0.04	[illegible]	[illegible]	[illegible]	[illegible]
AZ	0.03	0.031	0.03	[illegible]	[illegible]	[illegible]	[illegible]
BZ	0.01	0.019	[illegible]	0.0229	[illegible]	[illegible]	[illegible]
G	40	45	50	55	60	65	70

Figure 2: (a) Table for Cutting Speed (rpm) (b) Table for Feed Rate (mm/min)

During the turning operation, each of the selected cutting fluids was applied to each workpiece through a double hose by flooding means. Thus, the temperatures of each steel samples during turning operation were taken with the aid of a portable digital thermocouple (shown in fig 3), which has a sensor that senses the cutting tool-workpiece temperatures at far distance or proximity over time during machining operation. The turning operation was interrupted after every experiment and value of the flank wear was measured using magnifying glass (SANDVIK Coromant) at 50x magnification.

Figure 3: Portable Digital Thermocouple (Handy-Type)

Again, spindle vibration was measured before, during and after machining of each workpiece (sample) using a Vibration Meter (SD Card Data Logger-VB 8206SD) shown in figure 4. It has the capacity (inform of sensor) to record the minimum and maximum spindle vibration over time.

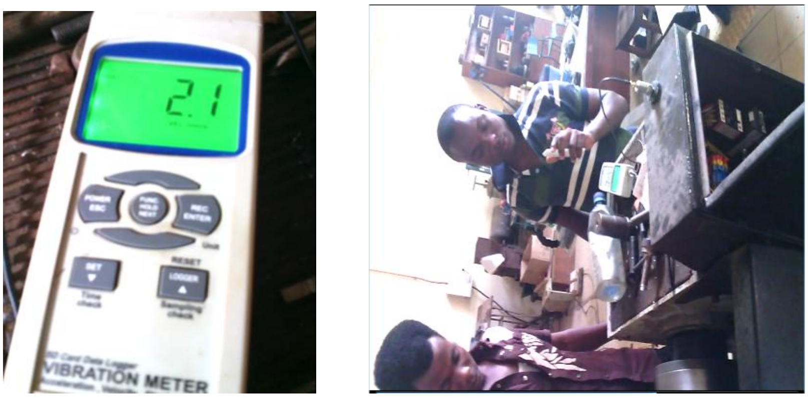

Figure 4: Portable Digital SD Card Data Logger Vibraton Meter (VB 8206SD)

a) **Tool Wear Measurement:** Flank wear was measured at 50x magnification using Magnifying glass (SANDVIK Coromant) shown in figure 5. Whenever a milling process was ended, the flank wear of the inserted tool was measured via a graduation scale embedded in the magnifying glass, and its value was recorded.

Figure 5: Magnifying Glass (SANDVIK Coromant)

Analysis/ Parametric Studies

In this present study, the performances of lard, tallow and mineral oil based cutting fluids were examined during machining operation of hypo-eutectoid steels. During milling operations, dependent variables like temperature of the workpieces, tool life, spindle power consumption, as well as their chip formation rates for the selected animal oil based cutting fluids were compared with that of conventional mineral oil based cutting fluids (MCFs) under different independent variables like cutting; speed (rev/min), feed rate (mm/rev) and depth of cut (mm).

(a) Spindle Power Consumption: The spindle power consumptions were obtained with the aid of the logger shown in figure 6. The logger has the capacity to read the current and the voltage of the milling machine used.

$$Spindle\ Power\ Consumption = Current(A) * Voltage(V)$$

$$P = I * V\ (Watts)$$

(1)

Figure 6: Logger Connected to the Centre Lathe via Electric Motor and Computer System

(b) Tool life: This is the period of time a tool cut satisfactorily to the time it requires re-grinding due to failure.

If the tool life values obtained from the experimental data are plotted on a natural log-log graph of cutting speed versus tool life, the resulting relationship is a straight line expressed in equation form called the Taylor tool life equation:

$$VT^n = C \qquad (1)$$

Where v = cutting speed; T = tool life; n and C are constants, whose values depend on cutting conditions, work and tool material properties, tool geometry, feed, depth of cut, and the tool life criterion used. These constants are well tabulated and easily available.

$$logV + nlogT = logC \qquad (2)$$

$$logV = -nlogT + logC \qquad (3)$$

Also from equation of a straight line; $y = mx + c$ (4)

Relating (1) to (4), $\mathrm{n = slope; C = intercepton\ the\ logV\ axis}$

The negative (-ve) sign in equation (3) shows a fall in logV against logT.

Thus, an expanded version of Taylor's tool life equation can be formulated to include the effect of feed, depth of cut and even work material properties.

$$VT^n * S^y * D^x = C \qquad (5)$$

Where V= cutting speed, T= tool life, D = depth of cut, S= feed rate; x and y are determined experimentally, they are arranged according to the order of importance. n and C are constants.

Using these parameters, (5) can be re-written as:

$$T = C^{\frac{1}{n}} * V^{\frac{-1}{n}} * S^{\frac{-y}{n}} * D^{\frac{-x}{n}} \qquad (6)$$

(c) Machine Removal Rate (MRR): This is the volume of the unwanted materials (chips) removed from the machined in a specified period of time

Note: Conversion formulae used for converting MRR (gm/sec) into MRR (mm3/min.) according to Papreja *et al.* (2014) [11] is:

$$MRR = (w_1 - w_2)/t \;\; gm/sec \tag{7}$$

$$MRR = \frac{[(w_1 - w_2)/t]}{Density\ of\ AISI1045\ Steel\ (kg/m^3)} * 1000 * 60\ mm^3/min \tag{8}$$

Density of AISI 1045 Steel = 7800kg/m^3

Where w_1 and w_2 are weight of the steel samples before (initial) and after (final) machining; t is the machining (logging) time.

Results and Discussion

The Experimental Results obtained during machining were plotted and discussed in detail in this section. The process parameters and the tool life were also examined to evaluate and compare the performances of the selected cutting fluids.

Mechanical Test Results

The mechanical tests like the hardness, test and impact test results are presented in Table 4.

Table 4: Mechanical Test Results

S/N		**Hardness Test (BRN)**				**Tensile Test (MPa)**	**Impact Test (J)**
	Mechanical Test	**1st**	**2nd**	**3rd**	**Average**		
1		386.49	386.50	386.50	128.83	450.92	120
2		385.61	285.62	385.62	128.53	449.88	

Experimental Results

The experimental data results collected during the experiment while using all the cutting fluids, that is, lard oil cutting fluids (LOCFs), tallow oil cutting fluids (TOCFs), palm oil cutting fluids (POCFs), palm kernel cutting fluids (PKOCFs) and conventional mineral cutting fluids (MCFs) presented below:

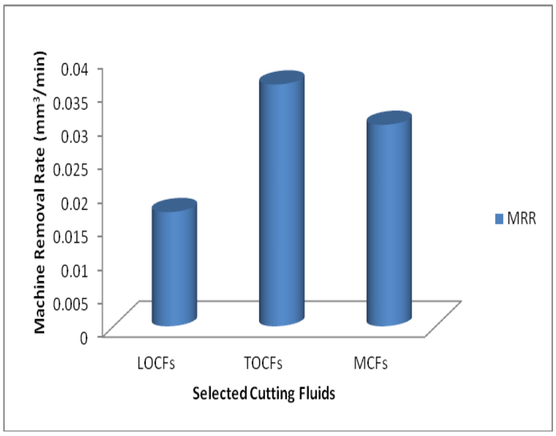

Figure 8: Plot of MRR against Selected CF

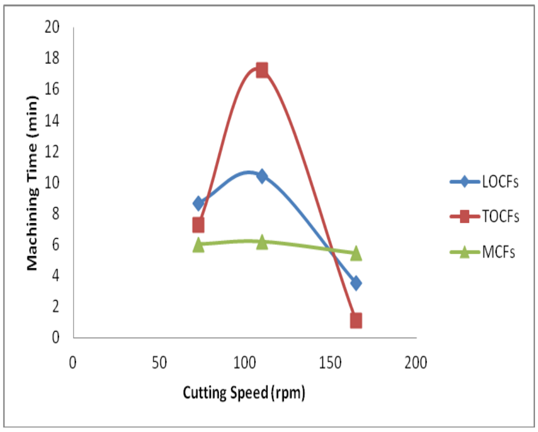

Figure 9: Plot of Machining Time against CS

Figure 8 showed that TOCFs produced the most removal rate. That is, more volume of materials was removed per minute using TOCFs. The chips thickness formed using TOCFs as cutting fluid (CF) 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. It could be concluded that LOCFs are better and could be substituted for MCFs in terms of MRR because lesser chips were formed.

Figure 9 showed the plot of machining time against the cutting speed (CS). The plot revealed that MCFs was the fastest. The steel sample was easily machined at the fastest time using MCFs. This is strictly followed by LOCFs. The steel sample took longer time of machining completion using TOCFs.

Figure 10 showed the plot of Max. Spindle Power Consumption (SPC) against Selected Cutting Fluids (CF). The plot revealed that MCFs consumed least spindle power. It could be inferred that LOCFs are the alternative cutting fluid in the absence of MCF because it consume almost the same spindle power with that of MCFs. The TOCFs consumed most. This was substantiated with the SPC’s data logger results in figs. 11 to 19.

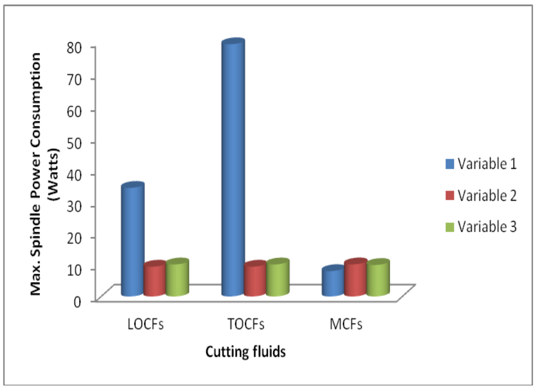

Figure 10: Plot of Max. SPC against Selected CF

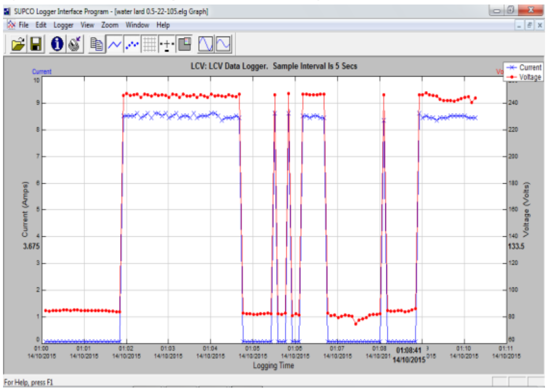

Figure 11: Data Logger Display of SPC at logger time interval under Variable 1 for LOCFs

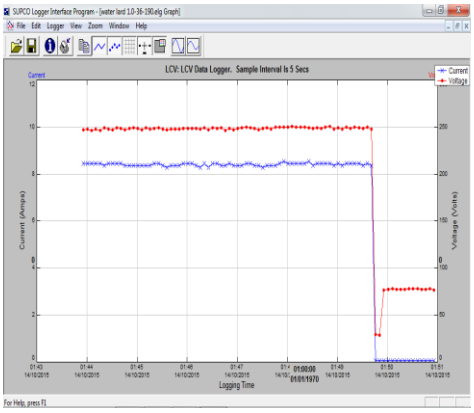

Figure 12: Data Logger Display of SPC at logger time interval under Variable 2 for LOCFs

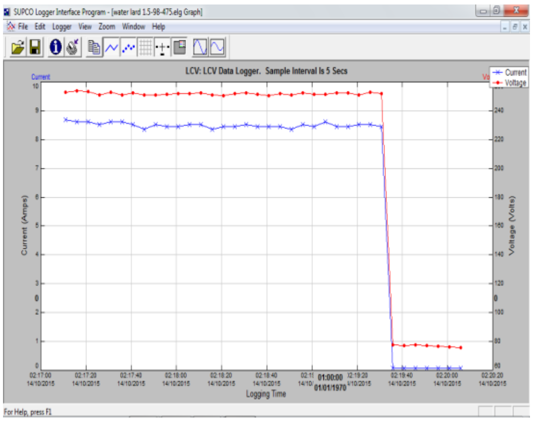

Figure 13: Data Logger Showing SPC at logger time interval under Variable 3 for LOCFs

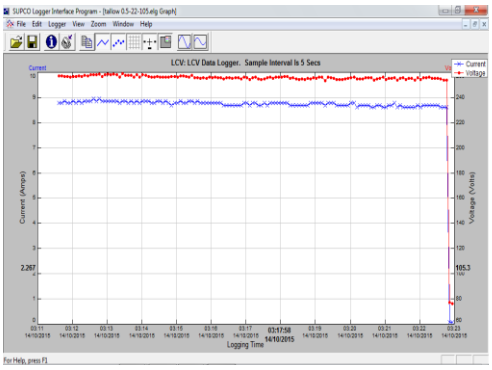

Figure 14: Data Logger Display of SPC at logger time interval under Variable 1 for TOCFs

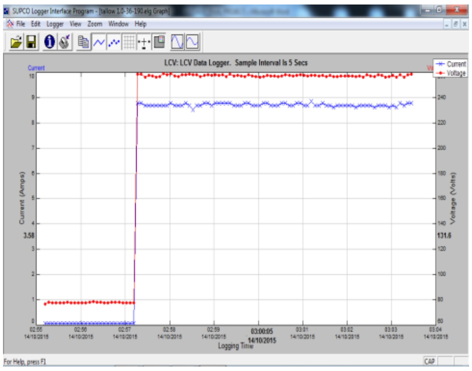

Figure 15: Data Logger Display of SPC at logger time interval under Variable 2 for TOCFs

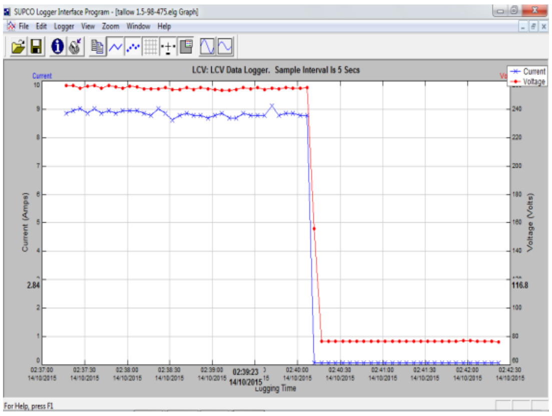

Figure 16: Data Logger Display of SPC at logger time interval under Variable 3 for TOCFs

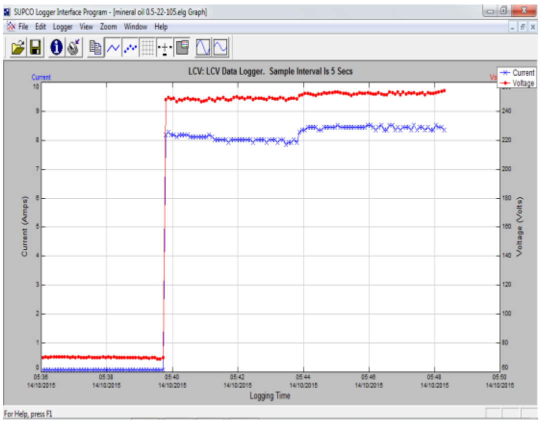

Figure 17: Data Logger Display of SPC at logger time interval under Variable 1 for MCFs

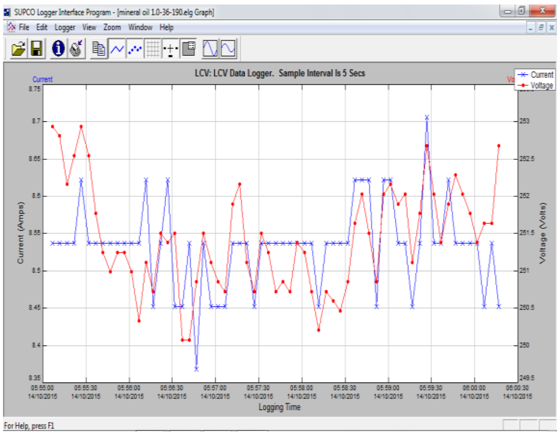

Figure 18: Data Logger Display of SPC at logger time interval under Variable 2 for MCFs

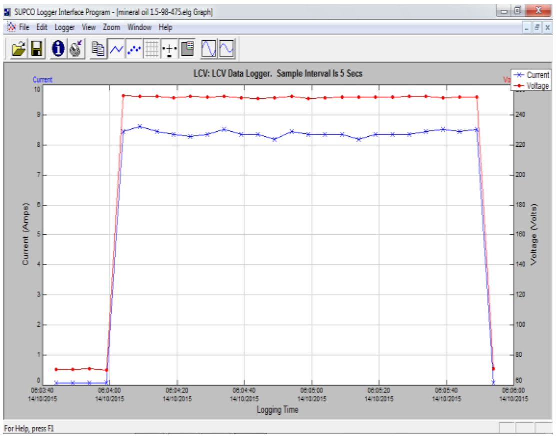

Figure 19: Data Logger Display of SPC at logger time interval under Variable 2 for MCFs

Conclusion

Cooling and lubrication in machining are important in reducing the severity of contact processes at the cutting tool-workpiece interface. This study focuses on experimental method for investigating the influence of some selected cutting fluids on some certain machining parameters like tool life, spindle power consumption, tool-workpiece temperature, machine removal rate, and logger time etc. during the turning operations of hypo-eutectoid steels. Experimental results clearly showed that conventional mineral oil based cutting fluids might be replaced with animal oil based ones like LOCFs and TOCFs as they give better performance.

Conclusively, the following salient features were achieved:

i. The LOCFs showed better performance when compared to MCFs at a variable combination of 73rpm, 3.0mm and 0.22mm/min cutting speed, depth of cut and feed rate, respectively.
ii. LOCFs are the alternative cutting fluid in the absence of MCF because it consumes an equivalent amount of spindle power with that of MCFs.
iii. The cooling property of the selected cutting fluids offers competitive performance with that of conventional mineral-based oil, as shown by the narrow temperature difference between the values obtained.
iv. The chips thickness formed using TOCFs 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. This substantiates the results obtain in Sharafadeen and Jamiu (2013).
v. TOCFs are more time consuming than any other forms of cutting fluids.
vi. The depth of cut, feed rate and cutting speed had a greater influence on the tool wear.

It has been established that ecology-friendly animal-based oils like LOCFs and TOCFs 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, better performing cutting fluids could be obtained.

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