ACTA METALLURGICA SLOVACA
2022, VOL. 28, NO. 1, 10-13

OPEN ACCESS
SCICELL

RESEARCH PAPER

PERFORMANCE EVALUATION OF COCONUT OIL BASED CUTTING FLUID WITH BIODEGRADABLE ADDITIVES ON CYLINDRICAL TURNING OF AISI 1040 CARBON STEEL

Segun M. Adedayo[1], *Bright K. Omoshola* [1], *Peter O. Omoniyi*[1,2*]

[1]Department of Mechanical Engineering, University of Ilorin, P.M.B. 1515, Ilorin, Nigeria
[2]Department of Mechanical Engineering Science, University of Johannesburg, 2092, Johannesburg, South Africa

*Corresponding author: Omoniyi.po@unilorin.edu.ng, tel.: +27622635779, Engineering and the Built Environment/University of Johannesburg, 2092, Johannesburg, South Africa

Received: 04.11.2021
Accepted: 08.02.2022

ABSTRACT

This article analyzed the effect of coconut oil-based cutting fluid with emulsion properties of 5%. The cutting fluid was evaluated by comparing it with conventional cutting fluid (Petroleum Based). Machining temperature at the tool-workpiece interface was measured during straight turning operation on CNC machine at various cutting speeds, depths of cut, and fixed feed rate of 7.5 mm/min for 15 minutes. The Response Surface Methodology (RSM) was also used to determine the machining parameters' effect on each cutting fluid's temperature at the tool-workpiece interface. It was observed that the developed coconut cutting fluid outperformed the other cutting fluids as a coolant at all experimented speeds, with a maximum temperature of 63.5 °C at the working zone as against 90.6 °C observed for conventional cutting fluid and 163.8 °C for dry turning. The viscosity values obtained from the developed cutting fluid between 40 °C and 100 °C show the tendency of the developed cutting fluid to maintain its lubricity at a higher temperature. Depth of cut was also observed to have a significant effect on the temperature at the tool-workpiece interface.

Keywords: Carbon Steel; Cutting Fluid; Cylindrical Turning, Lubricity, Machining

INTRODUCTION

Steel has its application in numerous industries such as chemical, railway, military, and automobile. This material often needs to be machined into different sizes and shapes [1], [2]. Cutting fluids are germane to obtaining a suitable surface finishing and reducing friction between the workpiece and the cutting tool. It helps remove and reduce heat during a machining operation. Furthermore, it extends the cutting tool life and reduces machining costs [3–5].

Conversely, the introduction of cutting fluid, which is petroleum based in machining, could result in the formation of smoke, mist, and release of gases, which could pose a danger to the health and safety of operators around [6]. However, dry machining and minimum quantity lubricant (MQL) machining have been developed to overcome the danger the gases from cutting fluids possess. However, chip transportation became a significant challenge to this technique due to heat accumulation from chips within the working environment. Also, there is a need for special cutting tools with special coatings due to the heat experienced during this process [1], [7]. Furthermore, these techniques are not economically viable in cases where there is a need for tight tolerances, high accuracy, and high dimension due to the destructive effects they have on the cutting tools [8–11].

Studying the temperature generated within the tool-workpiece environment is of paramount importance because temperature affects the shear deformation and increases stress concentration in the workpiece and the cutting tool [9], [12–14]. To mitigate the temperature buildup within the machining environment, cutting fluids are developed to cool and serve as a lubricant within the interface [15], [16]. Researchers have developed numerous bio-based cutting fluids, but their effectiveness is based on workpiece materials and tool material. Vegetable oil based cutting fluids have been reported to be beneficial due to their relatively low flash point of 210 ºC [17]. Due to the limitations of the dry and petroleum based cutting fluid as coolant, researchers have found coconut oil based cutting fluid to improve the surface roughness, lower temperature of both cutting tools and workpiece at high turning speed [5], [7], [13]. Furthermore, there is sustainability in using these vegetable oil products since they are biodegradable, renewable, and non-toxic. The unique properties of coconut oil, such as its ability to remain a white crystalline solid at 20 ºC, flash point around 294 ºC, viscosity index of 130 and cetane number of 37, coupled with its density of 0.93 g/cm^3 makes it a good oil for machining [13]. Vegetable oils which have been used in machining includes soyabeans oil, sunflower oil, rapeseed oil, jatropha curcass oil, olive oil, neem oil. However, the cost and sustainability of these oils have surpassed that of the coconut oil based cutting fluid [18].

The optimization of machining parameters has been carried out by several authors using different methodologies. The most popular methods used were the Response Surface Methodology (RSM) [8], Taguchi [19], Particle Swam Optimization (PSO), and Bacterial Foraging Optimization (BFO) [8]. These optimization techniques have proved efficient in establishing various relationships among the machining parameters.

Therefore, this article aims to develop bio-based cutting fluids that are cost-effective, readily available, and less corrosive and determine the effects of the turning parameters on machining temperature by adopting the RSM. Also, the objectives are to compare the effectiveness of the coconut oil-based bio-cutting

DOI: 10.36547/ams.28.1.1256

fluid with dry machining and the use of petroleum based cutting fluid on the tool-workpiece interface temperature.

MATERIAL AND METHODS

Material preparation

The turning operation on AISI 1040 Carbon steel with chemical composition and other operating parameters are presented in **Table 1**. During machining operation, the workpiece was clamped to a three-jaw chuck, with the tailstock supporting it. Before experimenting, a trial turning pass was done to remove the oxide layer formed on the workpiece and have a regular surface.

The cutting tool-workpiece interface temperature was measured with the aid of a thermocouple attached to a data logger. The thermocouple was attached to the cutting tool insert 5mm away from the tool nose to form the cold junction. The attachment was done by carefully scribing on the tool insert using a scriber and then attaching the hot junction of the thermocouple to the tool insert-workpiece interface using paper tape. The whole assembly was then insulated with tire-tube material rigidly wrapped around the paper tape by another layer of paper tape and a binding wire. Then the temperature was logged on the data logger as the machining operation was carried out [20], [21]. The experimental setup and its schematics are shown in **Figure 1a** and **b**.

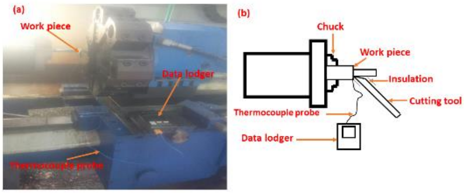

Fig. 1 (a) Experimental setup (b) Schematics of experimental setup

Table 1 Summary of materials, cutting conditions, cutting parameters, tools, and methods

Work Specimen	
Material Chemical Composition **(Optical electron Spectrometer)**	AISI 1040 Carbon Steel. (Fe = 98.6%, C = 0.380%, Mn = 0.697%, S = 0.64%, P = 0.00052%)
	Physical and Thermal Properties
Density	7.85 g/cc
Elastic Modulus	200 GPa
Poisson's Ratio	0.3
Melting point	1521 ºC
Thermal Expansion Coefficient	11.3 µm/mºC
Thermal Conductivity	51.9 W/mK
Dimension	Dia. = 50 mm, L = 135 mm
Hardness	93 HRB
Machine tool	
Machine Type	CNC Lathe, AJAX – EV 310
Cutting Tool (Insert)	Carbide, SNMG 120408 QMH-13A, (ISO specification), Corner Radius = 0.7938, Clearance Angle Major = 0 º
Tool Holder	PSDN 2525M12 (ISO specification)
Operation	Cylindrical Turning
Feed rate	*f* = 7.5 mm/min
Machining Temperature	K-type Thermocouple with Datalogger
Cutting fluid formula	
Coconut oil	Base oil
Sulphur	Extreme Pressure Agent
Washing soap	Emulsifier
Water	Coolant

Formulation of the developed cutting fluid

The formulated coconut oil cutting fluid was chosen due to its biodegradability and good environmental impact. It was prepared in a 1-liter measuring beaker using 85% coconut oil, 10% liquid washing soap and 5% Sulphur. The sample is then mixed with water at a ratio of 1:5 at room temperature to obtain 700 ml and stirred using a magnetic stirrer for 30 minutes. The density, PH value, viscosity, and flash point of the sample were determined and presented in **Table 3**.

Turning Procedure

In order to ascertain the performance of each cutting fluid sample, three cutting conditions were employed; cutting speed, depth of cut, and constant feed rate, as planned using the central composite design (CCD) **Table 2**. During this process, the cutting fluids were applied directly to the tool-workpiece interface at a rate of 50 ml/min. Each turning operation was done for 15 minutes. After each experiment, the insert was changed for a new one. The point of application of the cutting fluids was carefully chosen to maximize heat loss, and the rate of flow was maintained uniformly throughout the experimental procedure [22].

Table 2 Experimental design

Parameters	**Levels**				
	-1.41421	-1	0	+1	+1.41421
Cutting Speed (*V*)(rpm)	167	250	450	650	733
Depth of Cut (*d*) (mm)	0.1	0.6	1.8	3	3.5

RESULTS AND DISCUSSION

Physico-mechanical properties of cutting fluids

Table 3 presents the properties of the formulated coconut oil-based cutting fluid. The coconut oil consists of 90% unsaturated fat, which creates a resistance to rancidity and is valuable in machining. When exposed to an oxidative environment, its insignificant weight gain helps improve its lubricity [20]. The flash point observed also indicates the ability of the oil to perform well in high temperature environment.

Table 3 Physico-chemical properties of formulated coconut oil cutting fluid and petroleum based cutting fluid

Physico-chemical Properties	Value	
	Coconut Oil	**Petroleum Based Cutting Fluid**
Density **(g/cm^3)**	1.07	1.2
PH Value	8.40	-
Viscosity**(cp) (@ 40°C)**	17.90	28.30
Viscosity **(cP) 100°C**	13.87	19.50
Flash point **(°C)**	224	180

Regression equation

Analysis of the results was performed using MINITAB version 17 software via RSM. Regression equations were developed based on the temperature of the cutting tool-workpiece under three cooling conditions; Dry Cutting (DC), Petroleum Based

DOI: 10.36547/ams.28.1.1256

Cutting Fluid (PBCF), and Coconut Oil Based Cutting Fluid (COBCF), are presented in equations (1-3).

Dry Cutting Condition

$$\mathit{Temperature}\quad (DC) = -24.3 + 0.17V + 84.9d - 0.000007V^2 - 10.44d^2 - 0.0425Vd \quad (1) \qquad R^2 = 0.8890$$

Petroleum Based Cutting Fluid Condition

$$\mathit{Temperature}\quad (PBCF) = -20 + 0.1812V + 40.21d - 0.000110V^2 - 4.82d^2 - 0.0198Vd \quad (2) \qquad R^2 = 0.9255$$

Coconut Oil Based Cutting Fluid Condition

$$\mathit{Temperature}\quad (COBCF) = 14.5 + 0.0453V + 15.01d + 0.000006V^2 - 0.75d^2 - 0.0127Vd \quad (3) \qquad R^2 = 0.8093$$

Analysis of variance (ANOVA) was used in determining the reliability of the regression equations. The value of R^2 close to 1 shows how significant the model is [7]. The ANOVA results for the temperature of the tool-workpiece under each cutting condition are presented in **Table 5**. The significance level for this research is set at 0.05. Therefore, if the P-value is equal to or less than 0.05, it is statistically significant. The depth of cut is observed to affect the cutting tool-workpiece interface temperature primarily, irrespectively of the cooling medium used (50-60%) followed by cutting speed (16-26%). Furthermore, the higher order of interactions shows no significant contribution to the model, irrespective of the cooling medium used, similar observations were reported by Obiko et al., [23].

Table 5 ANOVA results for the temperature of cutting workpiece under different cutting conditions

Interactions	Dry Cutting			
	Contr. (%)	F-Value	P-Value	Remarks
V	15.88	10.02	0.016	Sign.
d	59.92	37.80	0.000	Sign.
Vd	2.72	1.71	0.232	Insign.
V^2	0.13	0.00	0.961	Insign.
d^2	10.26	6.48	0.038	Insign.
Error	11.09			
Total	100			
	Petroleum Based Cutting Fluid			
	Contr. (%)	F-Value	P-Value	Remarks
V	18.64	17.52	0.004	Sign.
d	60.14	56.53	0.000	Sign.
Vd	2.44	2.29	0.174	Insign.
V^2	2.32	3.40	0.108	Insign.
d^2	9.01	8.47	0.023	Insign.
Error	7.45			
Total	100			
	Coconut Oil Based Cutting Fluid			
V	Contr. (%)	F-Value	P-Value	Remarks
d	25.79	9.47	0.018	Sign.
Vd	50.51	18.54	0.004	Sign.
V^2	3.71	1.36	0.282	Insign.
d^2	0.11	0.02	0.900	Insign.
Error	0.82	0.30	0.601	Insign.
Total	19.07			
	100			

Fig. 2-4 shows the surface plots for the interactions of cutting speed and depth of cut on the tool-workpiece interface temperature for each cooling medium, DC, PBCF, and COBCF, respectively. These charts show the concise relationship each parameter has with each other to obtain cutting tool-workpiece interface temperature. The chats were developed using data from **Table 5**.

From **Fig. 2**, it can be observed that increasing the depth of cut, with an increase in cutting speed, there is an increase in the temperature developed within the cutting tool-workpiece interface as observed by Abbas et al., [2], Venkatesh and Senthilvelan [14]. The increase in temperature could be attributed to the bulk of cutting chips formed around the cutting tool and workpiece. Also, stress concentration and plastic deformation of the material could be responsible for this increase in temperature. The lack of cooling media such as fluid or pressurized air also contributed to the high temperature observed in this condition.

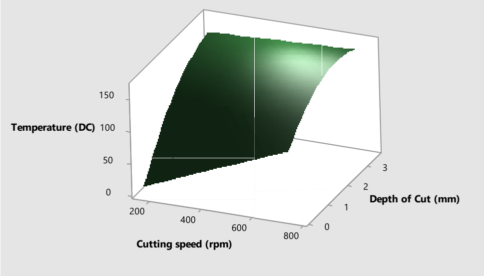

Fig. 2 Interactions of cutting parameters for dry cutting condition

Fig. 3 shows a similar trend observed in the dry cutting condition, except that lower temperatures are recorded in the cutting tool-workpiece interface, which is about a 41% reduction in temperature. This temperature reduction could be attributed to a cooling medium and rapid transportation of chips from the cutting region. Even though the cooling was insufficient for prolonged tool life, it still performed to an acceptable standard according to ASME 1952, as Singh and Bajpai [24] reported.

The trends observed in **Fig. 4** show lower temperatures at the cutting tool-workpiece interface than other cooling mediums used as cutting depth increases. However, a gentle slope was observed as cutting speed increases with an increase in cutting tool-workpiece temperature. Gosai and Bhavsar [21] reported a similar observation. There was a temperature reduction of 31% observed compared to the performance of the PBCF and a 60% reduction compared to the DC condition. The low temperature observed using COBCF could be attributed to the lubricity obtained in COBCF because of the level of Sulphur present in the cutting fluid [3] and the ability of the fluid to dissipate heat at a faster rate when compared to PBCF.

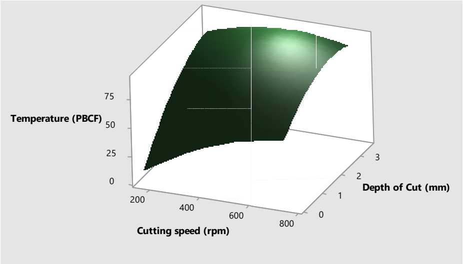

Fig. 3 Interactions of cutting parameters for petroleum based cutting fluid cutting condition

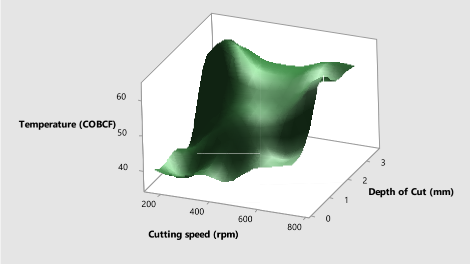

Fig. 4 Interactions of cutting parameters for coconut oil based cutting fluid cutting condition

CONCLUSION

It has been established that green cutting fluids derived from vegetable oils could successfully replace the conventional petroleum derived cutting fluids if properly formulated to induce desirable properties required for cutting fluids. The following can be concluded from this research work:

I. The developed cutting fluid improved the machining performance by reducing the machining temperature, lower than the conventional petroleum derived cutting fluid and dry machining.
II. Generally, cutting speed and depth of cut are attributed to the increase in cutting tool temperature.
III. Depth of cut is the parameter with the most influence on the tool-workpiece interface temperature.
IV. The developed cutting is recommended for turning operations on ferrous and non-ferrous materials.
V. It is recommended that further research be done to enhance the ability of green metalworking fluids as coolants and also evaluate the type of tool wear when coconut based cutting fluid is used.

Acknowledgments: The authors of this article wish to acknowledge late. Mr. Ibrahim, a technologist at the Central Workshop for the Department of Mechanical Engineering, University of Ilorin, for his support and expertise in the operation of the CNC lathe machine.

REFERENCES

1. P. Chauhan et al.: Lecture Notes in Mechanical Engineering, 2021, 199–207, https://doi.org/10.1007/978-981-15-5151-2_19.
2. A. T. Abbas et al.: Materials, 12(18), 2019, https://doi.org/10.3390/ma12183023.
3. J. Z. Zhang, P. N. Rao, and M. Eckman: International Journal of Modern Engineering, 12(12), 2012, 35–44.
4. M. Hadad and B. Sadeghi: Journal of Cleaner Production, 54, 2013, 332–343, https://doi.org/10.1016/j.jclepro.2013.05.011.
5. M. A. Xavior and M. Adithan: Journal of Materials Processing Technology, 209(2), 2009, 900–909, https://doi.org/10.1016/j.jmatprotec.2008.02.068.
6. Y. M. Shashidhara and S. R. Jayaram: Tribology International, 43(5–6), 2010, 1073–1081, https://doi.org/10.1016/j.triboint.2009.12.065.
7. S. Chinchanikar et al.: Procedia Materials Science, 5, 2014, 1966–1975, https://doi.org/10.1016/j.mspro.2014.07.529.
8. M. K. Gupta, P. K. Sood, and V. S. Sharma: Journal of Cleaner Production, 135, 2016, 1276–1288, https://doi.org/10.1016/j.jclepro.2016.06.184.
9. C. S. Akhil et al.: Journal of Mechanical and Civil Engineering, 13(2), 2016, 102–116, https://doi.org/10.9790/1684-130201108122.
10. E. Mirkoohi, P. Bocchini, and S. Y. Liang: International Journal of Advanced Manufacturing Technology, 102(5–8), 2019, 1557–1566, https://doi.org/10.1007/s00170-019-03296-y.
11. V. Varghese, M. R. Ramesh, and D. Chakradhar: Materials and Manufacturing Processes, 33(16), 2018, 1782–1792, https://doi.org/10.1080/10426914.2018.1476760.
12. L. B. Abhang and M. Hameedullah: International Journal of Engineering Science and Technology, 2(4), 2010, 382–393.
13. P. Vamsi Krishna, R. R. Srikant, and D. Nageswara Rao: International Journal of Machine Tools and Manufacture, 50(10), 2010, 911–916, https://doi.org/10.1016/j.ijmachtools.2010.06.001.
14. K. Venkatesh and T. Senthilvelan: Applied Mechanics and Materials, 813–814, 2015, 293–298, https://doi.org/10.4028/www.scientific.net/amm.813-814.293.
15. K. Kumar Gajrani and M. Ravi Sankar: Materials Today: Proceedings, 4(2), 2017, 3786–3795, https://doi.org/10.1016/j.matpr.2017.02.275.
16. A. Palanisamy and T. Selvaraj: Materials Today: Proceedings 5(2), 2018, 7708–7715, https://doi.org/10.1016/j.matpr.2017.11.447.
17. B. S. Kumar, G. Padmanabhan, and P. V. Krishna: Journal of Advanced Research in Materials Science, 19(1), 2016, 1–13.
18. K. Gupta, and R.F. Laubscher: Proc. Inst. Mech. Eng. Part B J. Eng. Manuf. 231, 2017, 2543–2560, https://doi.org/10.1177/0954405416634278.
19. L. B. Abhang and M. Hameedullah: Procedia Engineering, 38, 2012, 40–48, https://doi.org/10.1016/j.proeng.2012.06.007.
20. N. H. Jayadas and K. P. Nair: Tribology International, 39(9), 2006, 873–878, https://doi.org/10.1016/j.triboint.2005.06.006.
21. M. Gosai and S. N. Bhavsar: Procedia Technology, 23, 2016, 311–318, https://doi.org/10.1016/j.protcy.2016.03.032.
22. V. S. Sharma, M. Dogra, and N. M. Suri: International Journal of Machine Tools and Manufacture, 49(6), 2009, 435–453, https://doi.org/10.1016/j.ijmachtools.2008.12.010.
23. J. O. Obiko, F. M. Mwema, and M. O. Bodunrin: Manufacturing Review, 8(5), 2021, 1-13, https://doi.org/10.1051/mfreview/2021001.
24. Ramesh Singh and Vivek Bajpai: Handbook of Manufacturing Engineering and Technology, 2013, https://doi.org/10.1007/978-1-4471-4976-7.