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Investigation on Some Vegetable Oils as Alternative Metal Cutting Fluid

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Abstract: *This study determined the effects of some formulated vegetable (cotton, neem and groundnut) oil based cutting fluids on the cutting force, work piece temperature and surface finish during turning operation of mild steel. Taguchi method of experimental designed was used; the L9 orthogonal array was chosen with four factors, three levels and three replications. The factors were type of oil, cutting speed (45, 90, 125 m/min), feed rate (0.1, 0.2, 0.3 mm/rev), and depth of cut (0.50, 1.00, 1.50 mm). Cutting force required to machine the mild steel varied in the range of 633- 1230 N ; 663- 1470 N and 567-867 N for cotton oil, neem oil and groundnut oil based cutting fluids respectively as cutting speed increased from 45 to 125 m/min. The surface roughness of mild steel work piece machined with cotton oil based cutting fluid increase linearly. The surface roughness for groundnut oil increased from 45 to 90 m/min and decreased to 125 m/min, while that of neem oil based cutting fluids increased from 90 to 125 m/min. With increase in cutting speed, there was a corresponding increase in temperature of the work piece from 33.367 ^oC to 50.067 ^oC with cotton oil as cutting fluid. For neem oil, the temperature of the work piece decreased from 52.067 ^oC to 39.267 ^oC and then increased to 47.033 ^oC . It decreased from 44.567 ^oC to 33.167 ^oC when groundnut oil was used. The model equations developed are recommended for prediction of surface roughness, temperature, cutting force of work piece of the different cutting fluids (cotton, neem, and groundnut oil). Groundnut oil is recommended as a good cutting oil (fluid) for mild steel than the other two oils investigated.*

Keywords: *Cutting Fluids (CF), Cutting Force (cf), Surface Roughness (sr), Temperature (t), Vegetable Oils, Work Piece, Cutting Speed (cs), Feed Rate (fr), Depth of Cut (dc), Viscosity of Oil (vo).*

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I. Introduction

Metal Cutting

The knowledge of cutting forces developed in various machining processes under given cutting factors is of great importance to both the designer-manufacturer of machine tools and the user. Cutting forces are considered important parameters in turning operation, and they dictate the power required for machining (Fnides *et al*., 2008).

The cutting forces influence the deformation of work piece, dimensional accuracy, chip formation, tool wear, surface roughness, and machining system stability. Higher magnitude of forces lead to distortion in work piece, low dimensional accuracy, faster tool wear, poor surface finish, and undesirable vibrations. Cutting forces generated mainly depend on the depth of cut, cutting speed and type of cutting fluid. As the depth of cut increases, the magnitude of forces also increases. However, increase in cutting speeds reduces the magnitude of forces (Abdalla and Patel, 2006).

Metal cutting is done by a relative motion between the work piece and the hard edge of a cutting tool. Metal cutting could be done either by a single point cutting tool or a multi-point cutting tool. There are two basic types of metal cutting by a single point cutting tool. They are orthogonal and oblique metal cutting. If the cutting face of the tool is at 90 degree to the direction of the tool travel the cutting action is called orthogonal cutting. If the cutting face of the tool is inclined at less than 90 degree to the path of the tool then the cutting action is called oblique cutting (Oktem et al., 2005)

In the cutting of metals, work is done in the plastic deformation of the layer being cut at the primary shear plane, in overcoming friction on the tool- chip interface called the secondary shear plane and the layer adjoining the machined surface and the tool flank or the tertiary shear plane (Smith, 1993). The heat generated passes into the tool and reduces its hardness and makes it less wear- resistant. The use of cutting fluid ameliorates these adverse effects with the best fluid producing the best result. When lubricants are used, chips are thinner, meaning that a better lubricant should give a higher reduction of chip compression (Oxford, 2001), and reduction of chip thickness with speed and feed is an indication of reduction of cutting force, power consumed and temperature and that these depend on the cutting fluids used (Schmidt *et al.*, 1999). Fatty acids form salts (soaps) with metal ions because of the presence of terminal carboxyl groups. Their function may be one of effecting a dispersion of particulate matter and new trailing acids as well as acting as rust inhibitors (Oxford, 2001). Cutting fluids promote the reduction in heat evolution (by facilitating chip formation and reducing friction), and also absorb and carry away part of the generated heat, thereby lowering the temperature (Arshinov and Alekseev, 2003).

Ojolo *et al.*, (2008) experimentally determined the effect of some straight biological oils (groundnut oil, coconut oil, palm kernel oil and shear butter oil) on cutting force during cylindrical turning of three materials (mild steel, copper and aluminum) using tungsten carbide tool. The cutting variables considered during machining process were cutting speed, feed rate and depth of cut. Spindle speeds of 250, 330, 450 and 550rpm were used at a constant feed of 0.15mm/rev and 2mm depth of cut for each of the work piece. Their results showed that bio-oils were suitable for metalworking fluids, but the effects of the bio-oils on cutting force were material dependent. Groundnut oil exhibited the highest reduction in cutting force when aluminum was turned at a speed of 8.25m/min and feeds of 0.10, 0.15 and 0.20mm/rev, respectively. Palm kernel oil had the best result when copper was turned at feed lower than 0.15 mm/rev. However, at higher feeds, groundnut oil had the best result for copper. Coconut oil recorded the highest cutting force in all the three materials machined followed by shear butter oil and as such, were very mild in reducing cutting force during cylindrical machining. It was concluded that groundnut and palm kernel oils were effective in reducing cutting force during cylindrical turning of the three work pieces.

Ojolo and Ohunakin (2011) 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. The impact of lubrication on the coefficient of friction between the chip and rake face during turning operation, assuming a negligible friction between the flank and cut surface is measured. Experimental results show that aluminum at cutting speed of 4.15 m/s and rake angle 9 degrees gave a 33.3% reduction in coefficient of friction while brass and mild steel under the same cutting condition gave 7.9 and 13.8 % increase in coefficient of friction respectively. Findings at cutting speed of 4.15 m/s and depth of cut 1.5 mm gave 9.79 % reduction, 46.7 and 20.8 % increase in coefficient of friction for brass, aluminum and mild steel respectively while cutting speed of 4.15 m/s and feed 1.8 mm/rev gave a 9.2 % reduction, 30.4 and 14.5 % increase in coefficient of friction for brass, aluminum and mild steel respectively. Similar trend was observed by varying the cutting conditions on the work parts through different selected values. The effect of palm-kernel oil as a metal cutting lubricant is more pronounced on aluminum than brass and mild steel.

Obi et al. (2013) studied the effects of vegetable oils (cotton seed oil, palm oil, groundnut oil and shear butter oil) used as lubricants in the turning operation of aluminum under varying spindle speeds (90, 125, 180, 250, 355 rev/min), depths of cuts (1, 1.5, 2, 2.5, 3 mm) and feeds rates (0.1, 0.2, 0.3, 0.4, 0.5 mm/rev) and the result compared with kerosene. The parameters investigated are the chip thickness ratio, surface finish and surface temperature. Their performance when compared with conventional soluble oil has shown that, they can perform the same function as imported ones in the machining of aluminum. They reduced chip thickness ratio, improved surface finished and exhibited good cooling behavior at the work piece interface. This performance is due to their high viscosities and the presence of surface active agents such as stearic acid and halogens such as chlorine which help to reduce surface energy of a liquid and increase its wetting ability or oiliness.

Cutting fluids based on minerals oils are normally used for their low costs and chemical stability. Mineral oils based cutting fluids presently used have adverse effects on the operator and the environment compared to the environmentally friendly vegetable- based cutting fluids. The specific objectives of the research are: to determine the physicochemical properties of some potential cutting oils, to formulate soluble cutting fluids separately from some vegetable oils, to measure the cutting force during machine operation, and to carry out performance evaluation of the developed cutting fluids in turning operation based on the surface finish and amount of heat generated during machining operation.

II. Materials And Methods

These chapter discuss the materials and methods used for the study. Experimental measurement of the cutting forces and temperature in turning parts made of mild steel was carried out in the laboratory of the Department of Mechanical Engineering, University of Benin, Edo State, Nigeria.

Equipment

The main equipment used for the study were: Lathe Machine, Dynomometer, Infra –red- thermometer, and TM 8810 digital surface finish roughness tester.

Materials

The materials used for the study include Mild steel work piece, and Vegetable oils Neem oil was obtained from Michika Local Government Area, Groundnut oil from Hong Local Government and Cotton oil from Afcot company, Ngurore.

Experimental Design

While the dependent variables use: Force and energy dissipated during cutting, temperature rise in the work piece and Surface finish and surface integrity of the work piece.

The independent variables were: Cutting speed, feed and depth of cut and cutting fluids.
Taguchi method was used in the design of experiment specifically L9 with three levels was used with three replications.

Experimental Procedure

The major dependent parameter that was used to investigate the performance of each of the developed cutting fluid was temperature, the determinant being a measure of the ability of the cutting fluid to conduct heat away from the work zone during machining operation.

A work piece of 0.034 m diameter and length of 0.06 m was inserted in a 4-jaw chuck and was tightened in the jaws until they gripped the work piece. The work piece was then rotated to ensure that it fits well at its seat. Work piece was kept as parallel as possible with the center line of the lathe. A HSS tool was tightly clamped in the tool holder. The angle of the tool holder was adjusted properly so that the tool remained approximately perpendicular to the side of the work piece. Turning was carried out on the work piece. The cutting force was determined using dynamometer attached to the cutting tool, the temperature was measured with an infra-red thermometer and a surface finish TM 8810 digital roughness tester was used to ascertain the surface finish.

III. Results and Discussion

The results of evaluation of machining indices of mild steel using various process parameters (cutting speed, feed rate and depth of cut) as well as types of cutting fluids are given in Table 1, While tables are the summaries of ANOVA.

Effects of Cutting Speed on Cutting Force

The experimental results are presented in Figure 1. It can be seen from the figure that there was an increased in cutting force required to machine the mild steel as cutting speed increase from 45 to 125 m/min for all the oils (Cotton, Neem and Groundnut) used. For cotton and neem oils, the cutting force at 45 and 90 rpm were the same but that of neem oil increased rapidly at 125 m/min. The cutting force for groundnut oil decreased from 45 m/min to 90 m/min and then increased at 125 m/min. The lowest cutting force (267 N, 90 m/min), was obtained with groundnut oil as the cutting fluid which might be due to its good viscosity even at highest temperature (Lawal *et al.,* 2012) and the lowest in neem oil (1470 N, 125 m/min). Similar results were reported by Abdalla and Patel (2006), Adegbuyi *et al.* (2010) and Sharafadeen and Jamiu (2013). The regression models for the cutting fluids used with respect to cutting force and the coefficient of determination $r^2$are expressed as:

$$CF = 1113 - 1.25cs + 282fr + 538dc - 125vo \qquad r^2 = 0.99$$

Table 1: Average Cutting Force for work piece with Cotton oil, Neem oil and Groundnut based cutting fluid

Cutting speed (m/min)	Feed rate (min/rev)	Depth of cut(mm)	Cutting force (N)
45	0.1	0.5	633
90	0.2	1.0	867
125	0.3	1.5	1230
125	0.2	0.5	633
45	0.3	1.0	867
90	0.1	1.5	1470
90	0.3	0.5	567
125	0.1	1.0	267
45	0.2	1.5	867

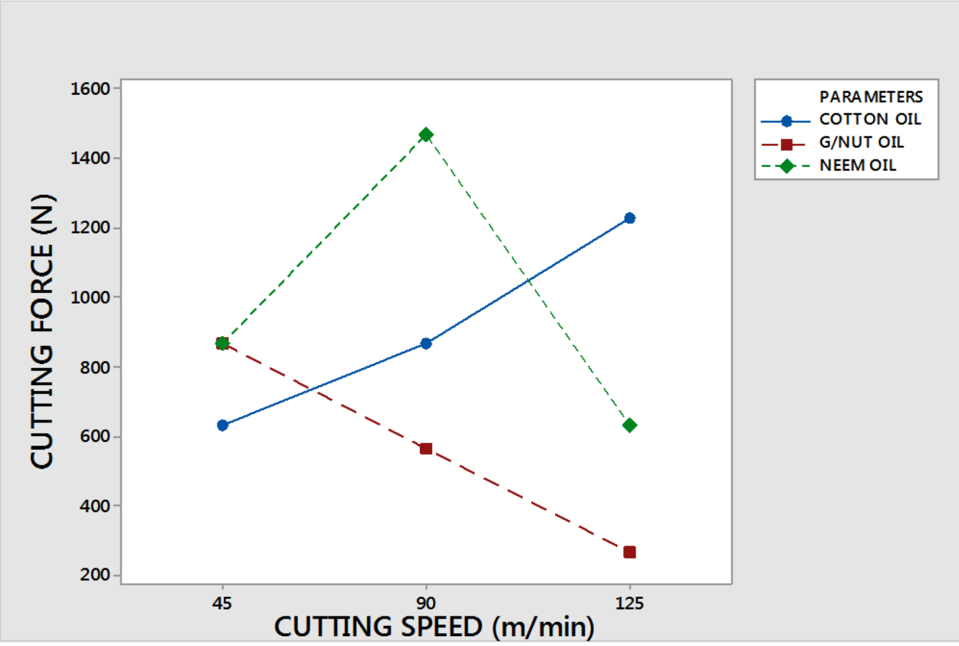

Figure 1: Relationship between cutting speed and cutting force

Table 2: Analysis of variance for cutting force

Oil	Factors	DF	SS	MS	F-Valve	P %
Cotton	Cutting Speed	2	1217.122	608.561	4.8701	99.98
	Feed Rate	2	0.008986	0.004493	3.5956E-5	0.001
	Depth of Cut	2	0.224639	0.1123195	0.0008988	0.018
	Error	16	1999.331	124.9582		
	Total	22	3216.6866			
G/nut	Cutting Speed	2	612.5	306.25	1.8813	99.98
	Feed Rate	2	0.005	0.0025	0.4333	0.001
	Depth of Cut	2	0.125	0.0625	0.3333	0.02
	Error	16	2604.557	162.7848		
	Total	22	3217.187			
Neem	Cutting Speed	2	2895.904	1447.952	72.2182	99.997
	Feed Rate	2	0.018783	0.00939	0.000468	0.001
	Depth of Cut	2	0.046958	0.23479	0.00112	0.002
	Error	16	320.7950	20.049688		
	Total	22	3216.7847			

Effects of Cutting Speed on Surface Roughness

The experimental results obtained for surface roughness are presented in Figure 2. It can be inferred from the figure, that there was a linear upward increase in surface roughness on mild steel with cotton oil which implies a relative rough surface as cutting speed increases. However, the work piece machined with neem oil showed an increase in surface roughness from cutting speed of 45 to 90 m/min and a decrease from 90 to 125 m/min whereas that of groundnut oil showed a decrease from 45 to 90 m/min and an increase from 90 to 125 m/min. At 125 m/min, the surface roughness of both neem and groundnut oils were the same (1.467 µm) and less when compared to cotton oil (1.667 µm). From Figure 2, mild steel machined with groundnut oil as cutting fluid tends to have lower surface roughness at higher speeds than those machined using neem and cotton oils as cutting fluids. This is similar to the reports of Swarup and Pradip (2008), Kuram *et al.*, (2010) and Obi *et al.*, (2013). The regression models for the cutting fluids used with respect to surface roughness and the coefficient of determination r^2 are expressed as:

$$SR = 2.70 - 0.00877cs + 7.74fr - 0.264dc - 0.225vo \qquad r^2 = 1$$

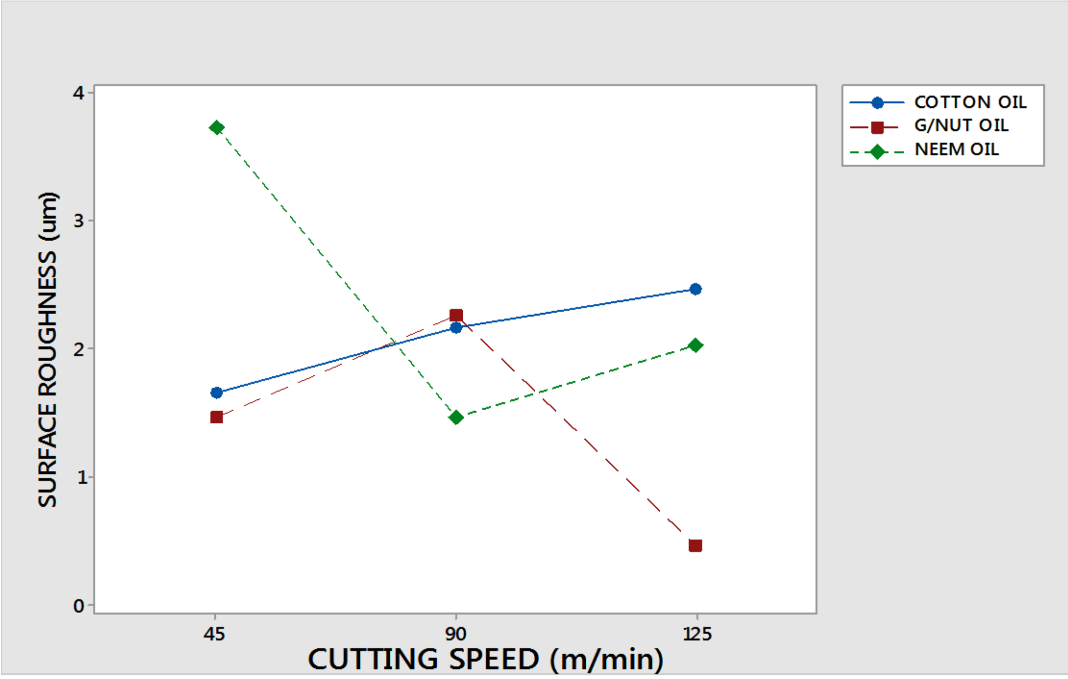

Figure 2: Relationship between Cutting Speed and Surface Roughness

Table 3: Analysis of Variance for Surface Roughness

Oil	Factors	DF	SS	MS	F-Value	P (%)
cotton	Cutting speed	2	3200.34	1600.17	1567.15	99.984
	Feed Rate	2	0.019592	0.009796	0.009594	0.001
	Depth of cut	2	0.489796	0.244898	0.2398	0.015
	Error	16	16.33714	1.02107		
	Total	22	3217.187			
G/nut	Cutting speed	2	16.6667	8.33335	0.04166	99.998
	Feed Rate	2	3.5E-18	1.7E-18	8.4986E-21	0.001
	Depth of cut	2	1.11E-16	0.555E-16	2.77E-19	0.001
	Error	16	3200.52	200.0325		
	Total	22	3217.187			
Neem	Cutting speed	2	92.37536	46.18769	0.23697	99.9679
	Feed Rate	2	0.001152	0.000576	2.9493E-6	0.0001
	Depth of cut	2	0.028791	0.014396	7.3712E-5	0.0310
	Error	16	3124.782	195.2989		
	Total	22	3217.187			

Effects of Cutting Speed on Temperature of work piece

Figure 3 present results obtained for the temperatures of the mild steel used in this study at the cutting speeds of 45, 90 and 125 m/min. The figure shows that with increase in cutting speed, there was a corresponding increase in temperature of the work piece with cotton oil as cutting fluid. For neem oil, the temperature of the work piece decreased from 52.067 ^{o}C to 39.267 ^{o}C at a corresponding speed of 45 m/min to 90 m/min and increased to 47.033 ^{o}c when cutting speed increased to 125 m/min. However, when groundnut oil was used, the temperature decreased from 49.567 ^{o}C to 44.567 ^{o}C at cutting speeds of 45 m/min and 90 m/min, respectively and decreased further to 33.167 ^{o}C at 125 m/min. The lowest and highest temperature of 33.167 ^{o}C and 52.067 ^{o}C, respectively were obtained at a cutting speed of 125 m/min using groundnut oil and neem oil as cutting fluid respectively. Groundnut oil was therefore found to be better cutting fluid as it absorbs more heat than the other oils investigated in this study. This result is similar to the results of Amrita *et al.* (2014), Khan *et al.* (2009) and Swarup and Pradip (2008). The regression models for the cutting fluids used with respect to temperature and the coefficient of determination r^2 are expressed as:

$$\text{Tempt} = 28.3 - 0.0180cs + 68.1fr + 4.47dc - 0.15vo \qquad r^2 = 1$$

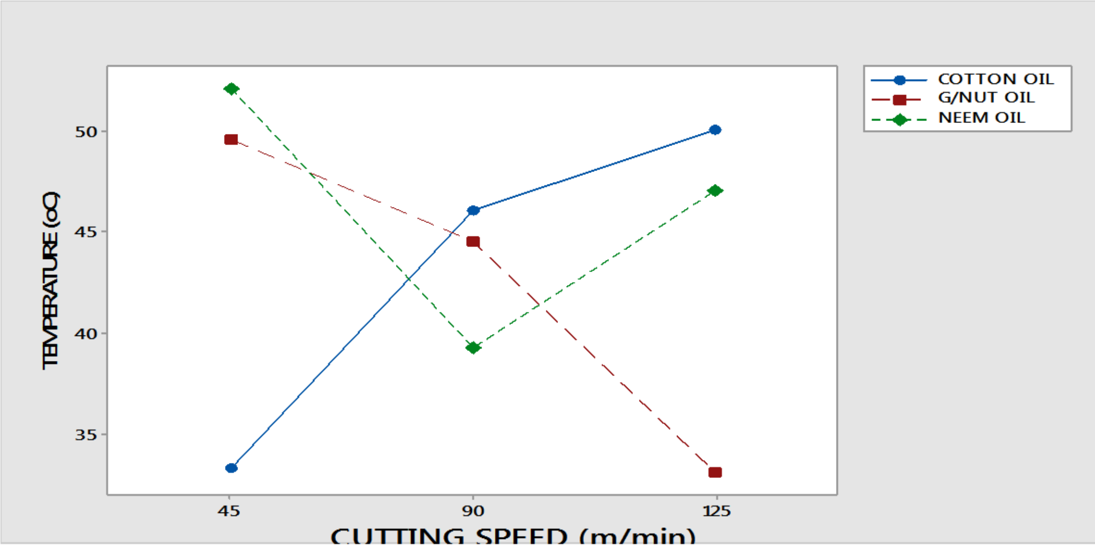

Figure 3: Relationship between Cutting Speed and Temperature

Table 4: Analysis of Variance for Temperature

Oil	Factors	DF	SS	MS	F-Value	P(%)
cotton	Cutting speed	2	3060.426	1530.213	156.660	99.984
	Feed Rate	2	0.018318	0.009159	0.00094	0.0005
	Depth of cut	2	0.457941	0.228971	0.02344	0.0001
	Error	16	156.2841	9.767756		
	Total	22	3216.667			
G/nut	Cutting speed	2	167.1078	83.5539	0.4383	99.972
	Feed Rate	2	0.001769	0.0008845	4.64E-6	0.002
	Depth of cut	2	0.04423	0.022115	0.00012	0.026
	Error	16	3050.033	190.6206		
	Total	22	3216.667			
Neem	Cutting speed	2	948.8956	474.4478	3.34693	99.98
	Feed Rate	2	0.00752	0.003626	2.558E-5	0.001
	Depth of cut	2	0.181301	0.906505	0.006395	0.019
	Error	16	2268.099	141.7562		
	Total	22	3216.667			

IV. Conclusion

The materials used for the study include Mild steel work piece, and Vegetable oils Neem oil was obtained from Michika Local Government Area, Groundnut oil from Hong Local Government and Cotton oil from Afcot company, Ngurore. In conclusion Groundnut oil is recommended as a good cutting oil (fluid) for mild steel than the other two oils investigated. The regression model equations have coefficient of determination r^2 for all the parameters investigated were above 0.95 and accurately describe the machining processes using cotton, neem and groundnut oils based cutting fluids.

V. Recommendations

1. The model equations developed are recommended for prediction of surface roughness, temperature, cutting force of work piece of the different cutting fluids (cotton, neem, and groundnut oil).
2. Groundnut oil is recommended as good cutting oil (fluid) for mild steel as it is better than the cotton and neem oils

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