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Study of Rake Face Action on Cutting Using Palm-Kernel Oil as Lubricant

[1]S.J. Ojolo and [2]O.S. Ohunakin

[1]Mechanical Engineering Department, University of Lagos, Lagos. Nigeria
[2]Mechanical Engineering Department, Covenant University, Ota, Ogun State. Nigeria
Corresponding Author: S.J. Ojolo

Abstract

The work investigates 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 4.15m/s and rake angle 9^o gave a 33.3% reduction in coefficient of friction while brass and mild steel under the same cutting condition gave7.9 and 13.8% increase in coefficient of friction respectively. Findings at cutting speed of 4.15m/s and depth of cut 1.5mm 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 4.15m/s and feed 1.8mm/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 workparts 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.

Keywords: cutting speed, feed rate, depth of cut, palm-kernel oil, lubricant

INTRODUCTION

Metal cutting or machining produces desired shape, size, and surface finish through the removal of chip from a rough block of material (DeGarmo et al., 1984). Since chip formation is the heart of metal cutting, adequate understanding of the chip-forming process is needed if improvement and better utilization of machining is to be achieved. Cutting is accomplished through a joint action of cutting force and normal force and since there is no movement in the normal direction, the entire power is consumed by the cutting force to overcome frictions and to break down metal bonds. The work piece is deformed plastically in 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 workpiece, cutting tool, chips and the cutting fluid. According to Cakir et al. (2007), approximately 60% heat is generated in the shear region of the workpiece and 80% of this heat goes into the chips, hence a properly applied cutting fluid at the cutting zone absorbs the heat away, hence, temperature in machining depends upon the balance between the rate at which heat is generated and the rate it is dissipated (Silva and Wallbank, 1999).

The rubbing action or friction of the chip as it moves across the rake face of the tool generates heat, so also the friction between the flank and the cut surface. The magnitude of this heat depends on the length of contact of the chip while travelling along the rake face. Huang et al. (1999), showed that, increasing the depth of cut will either increase or decrease the tool force, tangential force and temperature thereby making frictional force and shear force the main mode of heat generation in any turning operation, therefore, cutting operation can be affected by controlling the contact length of the tool/chip interface. A study of the effect of the cutting tool rake angle on main cutting force showed that the main cutting force was reduced by increasing rake angle in positive values and was consequently increased by increasing rake angle in negative values (Gunay et al., 2005). It is further believed that cutting feed has the greatest influence on tool wear and tool life, hence, increasing cutting feed will result into an increase in tool wear, which invariably shortens the tool life. According to Astakhov (2006), there is an optimal cutting temperature in any cutting operation within which an increase of the cutting feed will result into a prolonged tool life while the influence of depth of cut on the tool wear rate is minimal if the machining is done within the optimum cutting regime. Therefore, reducing friction through application of lubricants, results in a reduction of the heat generated. Lubrication, increases shear angle which will translate into reduction of heat (low shear angle results in increase in heat and vice-versa); hence, reduction of friction coupled with the removal of heat from the chip-tool-work piece interface, will prolong the operational lifetime of cutting tools. Lubricants in machining are referred to as cutting fluids, which can be straight oils, water miscible fluids, gasses and paste or solid lubricants. Water is best for cooling but a very poor lubricant while oil has great lubricating tendencies and poor cooling ability (Sokovic and Mijanovic, 2001). Hence, improved lubricating capacity of cutting fluids will greatly reduce friction and heat generation, thereby lowering the overall machining temperature. Among the liquid based lubricants are vegetable oils which are plant-based products and mineral oils. Vegetable oil-based cutting fluid has been shown to perform better than mineral oil in lubricity, 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 workpiece being handled (Machine shop, 2009; Woods, 2005; and Ojolo et al., 2008).

MATERIALS AND METHODS

Materials used for the experiment

The following materials were used for the research work: Colcherster Mastiff 1400 lathe machine, force dynamometer, high speed steel cutting tool (16mm x 16mm x 200mm), lubricant (2 – litre palm kernel oil), mild steel, brass and aluminium alloy rods with dimension 50mm x 300mm respectively. The process parameters used include: (i) lathe spindle of 135,185,245 and 330 rev/min, (ii) cutting speed of 1.7, 2.33, 3.08 and 4.15 m/s, (iii) feed rate of 1, 1.5, 1.8 and 2.00 mm/rev, (iv) depth of cut of 0.5, 1, 1.5 and 2.00 mm, (v) rake angle of 5, 7, 9, and 11^o , (vi) turning operation was carried out without lubricant (dry condition) and with lubricant (wet condition) where the lubricant was being applied directly to the cutting zone.

Experimental Procedure

The turning operation commenced with the workpiece being mounted on the 3-jaw chuck of the lathe machine with the force dynamometer mounted on its bed. The dial gauges of the dynamometer were initialized and adjusted to torch the job slightly. During the turning operations, cutting forces of the three sample rods (brass, mild steel and aluminum alloys) were recorded under the dry and wet conditions using the dial gauge. Four machining parameters considered during the study were as follows: (i) cutting speed and rake angle were varied according to the stated values while depth of cut and feed rate remained at 2mm and 1mm/rev, respectively, (ii) cutting speed and feed rate were varied according to the stated values while rake angle and depth of cut remained at 11^o and 2mm, respectively, (iii) cutting speed and depth of cut were varied according to stated values , while rake angle and feed rate remained at 11^o and 2 mm/rev respectively.

Calculation of turning parameters

According to Ojolo *et al.* [10],

$$CS = \frac{\text{Dia of workpiece x lathe spindle rotational speed}}{4} \text{ (m/min)} \quad (1)$$

$$= \frac{D \text{ x } RPM}{4}$$

$$F = F_c \text{ Sin } \alpha + F_t \text{ Cos } \alpha \qquad (N) \qquad (2)$$

$$N = F_c \text{ Cos } \alpha - F_t \text{ Sin } \alpha \qquad (N) \qquad (3)$$

From Merchant’s force circle,

$$R = \sqrt{(F^2 + N^2)} \qquad (N) \qquad (4)$$

Resultant cutting force,

$$R = \sqrt{(F_c^2 + F_t^2)} \qquad (N) \qquad (5)$$

Coefficient of friction,

$$\mu = F / N = (F_t + F_c \tan \alpha) / (F_c - F_t \tan \alpha) \qquad (7)$$

CS = cutting speed, D = diameter of tool in mm, RPM = revolution per minute of the lathe spindle, F_c = cutting force (parallel to the cutting velocity), F_t = thrust force (perpendicular to the cutting velocity), F = tangent friction force of tool on chip, N = normal friction force of tool on chip, α = rake angle

RESULTS AND DISCUSSION

Analysis of palm-kernel as a lubricant reveals the performance to depend on the cutting parameters used. Table 1 shows the lubricant performance at cutting speed, rake angle, depth of cut and feed rate of 4.15m/s, 9^o, 1.5mm and 1.8mm/rev respectively.

Table 1: Analysis of lubricant performance

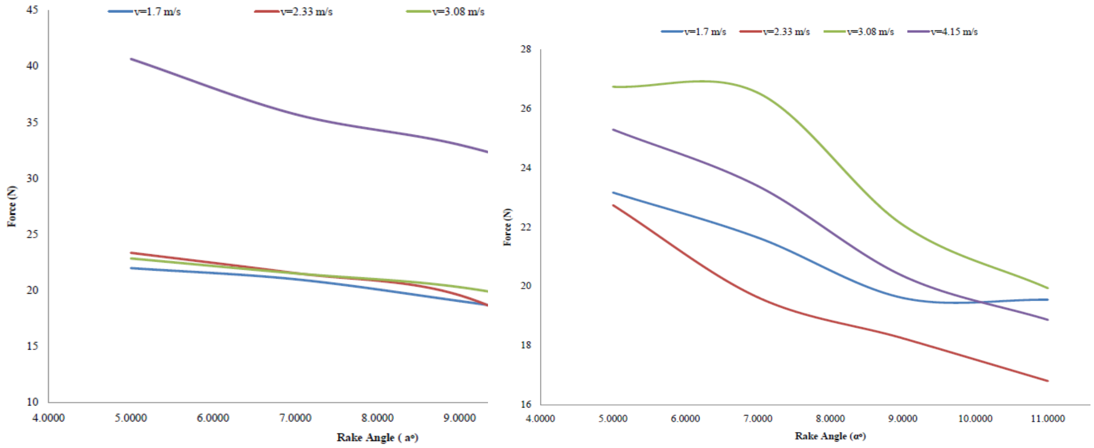
	RAKE ANGLE VARIATION			
	Coefficient of friction	Rake Angle	Cutting Speed	%
Material				
Aluminium	0.56	9^0	4.15 m/s	33.3 (reduction)
Brass	0.65	9^0	4.15 m/s	7.9 (increase)
Mild Steel	0.38	9^0	4.15 m/s	13.8(increase)
	DEPTH OF CUT VARIATION			
Material	Coefficient of friction	Depth of cut	Cutting Speed	%
Aluminium	0.94	1.5 mm	4.15 m/s	46.7 (increase)
Brass	0.53	1.5 mm	4.15 m/s	7.9 (reduction)
Mild Steel	0.50	1.5 mm	4.15 m/s	20.8 (increase)
	FEED RATE VARIATION			
Material	Coefficient of friction	Feed Rate	Cutting Speed	%
Aluminium	0.95	1.8 mm/rev	4.15 m/s	30.4 (increase)
Brass	0.64	1.8 mm/rev	4.15 m/s	9.2 (reduction)
Mild Steel	0.56	1.8 mm/rev	4.15 m/s	14.5(increase)

The relationship between rake angle and cutting speed of 1.70,2.33,3.08,4.15 m/s ,depth of cut of 2 mm and feed rate of 2 mm/rev is shown in figure 1. It can be observed from the graph that the higher the rake angle, the lower the cutting force. Hence, cutting force reduces by increasing the rake angle in positive values. The dry conditions (control experiments) have higher values of cutting forces than the wet conditions (lubricated experiments) for the aluminum, brass and mild steel respectively to show that the presence of lubricant reduced friction between the cutting tool and workpieces.

Figure 2 shows the relationship between depth of cut and cutting force for the three metals considered, at varying cutting speed of 1.7, 2.33, 3.08 and 4.15 m/s, rake angle of 11^{o} and feed of 2mm/rev. It can be observed from the trend that depth of cut increases with increasing cutting force; as the depth of cut increases, more energy will be required to cut off larger portion of workpiece thereby increasing the cutting force. Figure 3 shows an increasing trend between the cutting force and feed in both the dry and wet conditions for the three workpieces at rake angle of 11^{o}, depth of cut of 2mm and different cutting speeds of 1.7, 2.33, 3.08 and 4.15 m/s respectively.

The greater the feed, the higher the cutting force; increased feed results in more material removal from the workpiece, requiring more energy leading to increased cutting force. A low cutting force is experienced under the lubricated experiment than the control experiment for the three samples considered. However, aluminum showed an irregular pattern under the wet condition at the different cutting speeds.

a) Aluminum (dry) Aluminum (wet)



b) Brass(dry) Brass (wet)

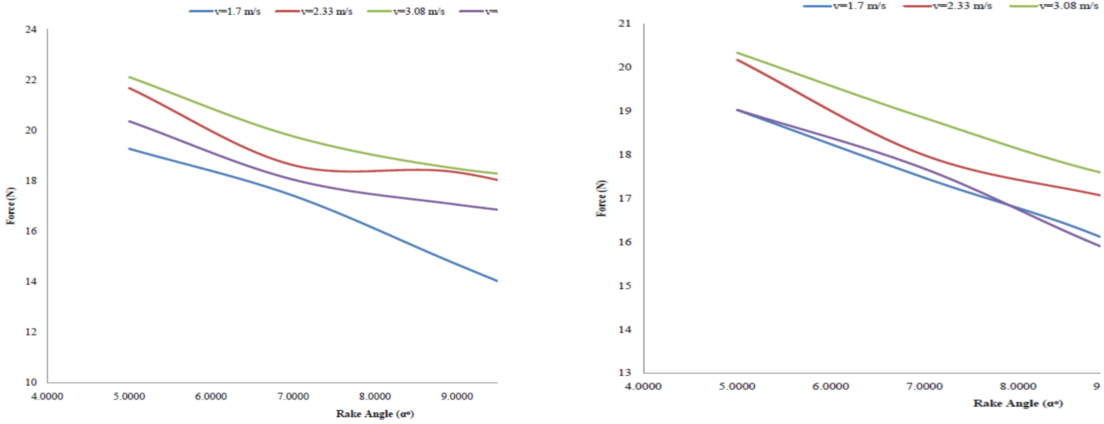
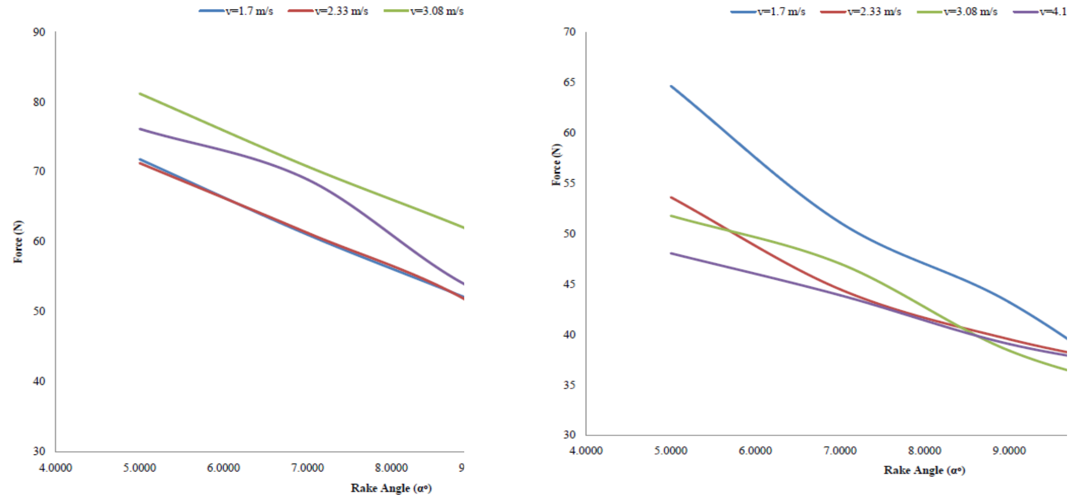
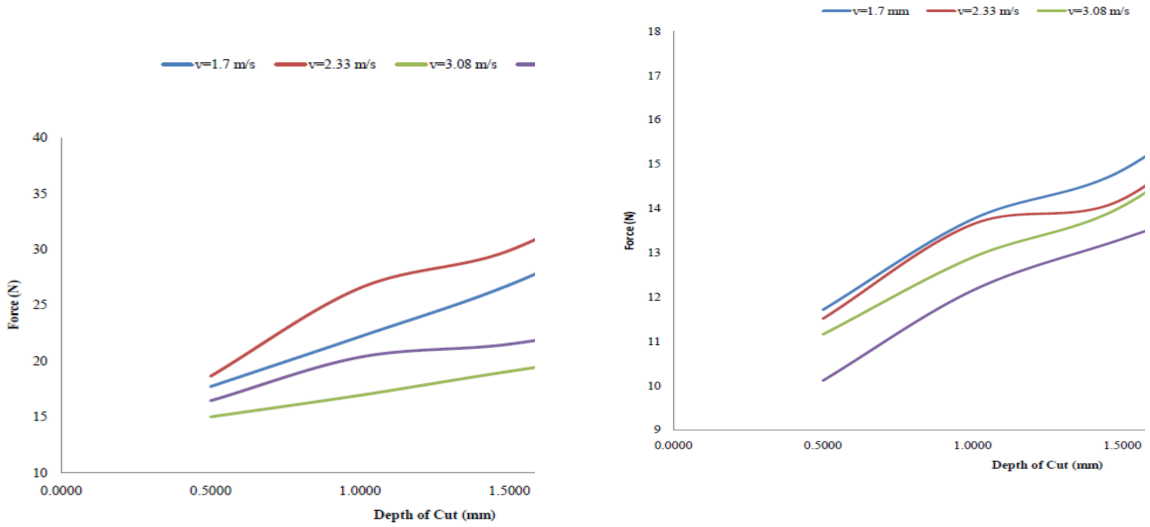


Fig 1a: Graph showing the rake angle against cutting force for a) Aluminum b) Brass in both the dry and wet conditions

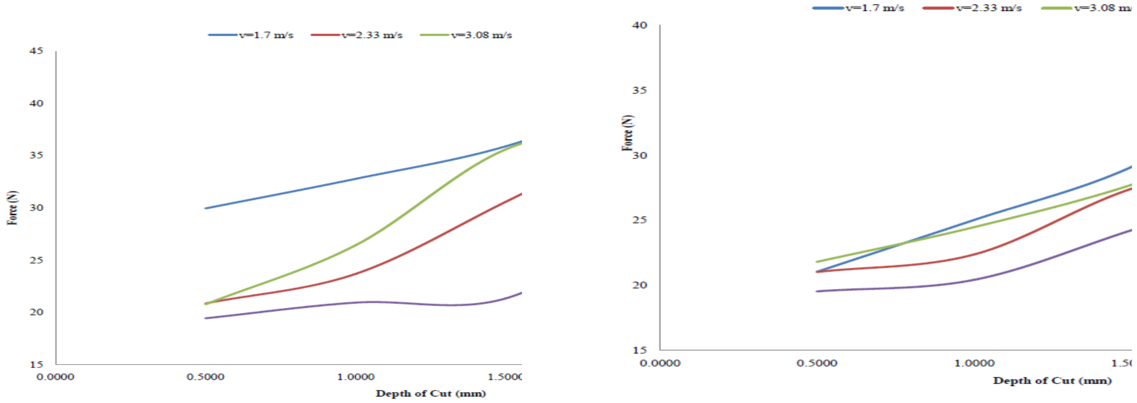


c) Mild steel (dry) Mild steel (wet)

Fig 1b: Graph showing the rake angle against cutting force for Mild steel in both the dry and wet conditions

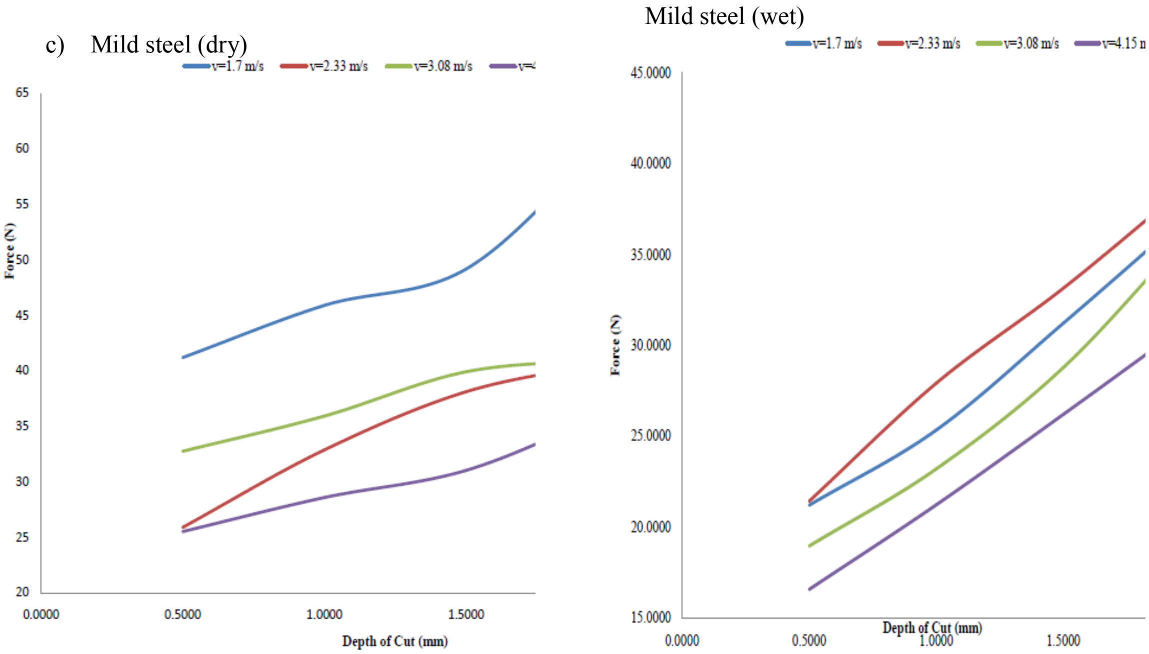


a) Aluminum (dry) Aluminum (wet)



b) Brass (dry) Brass (wet)

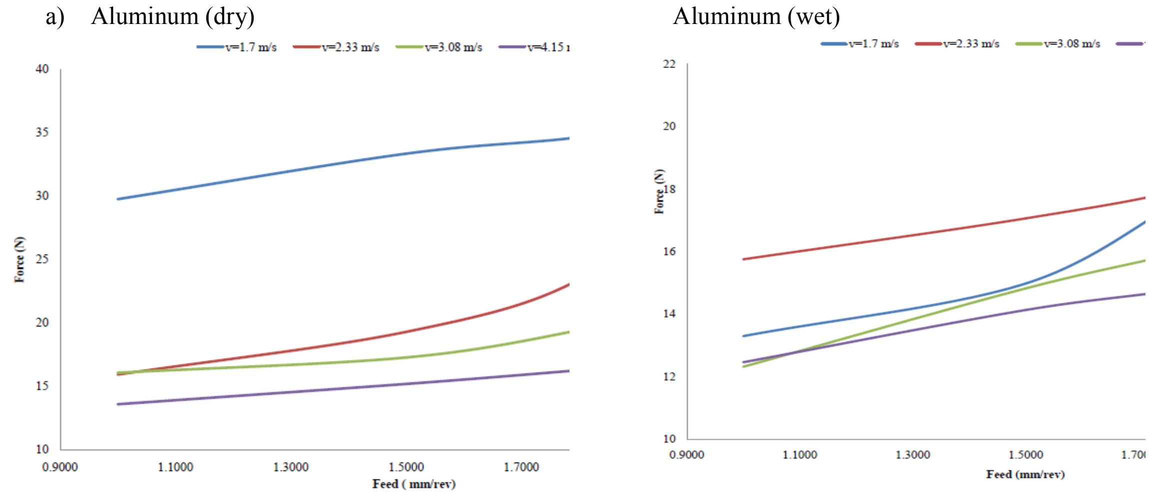
Fig 2a: Graph showing depth of cut against cutting force for a) Aluminum b) Brass and in both the dry and wet conditions



c) Mild steel (dry)

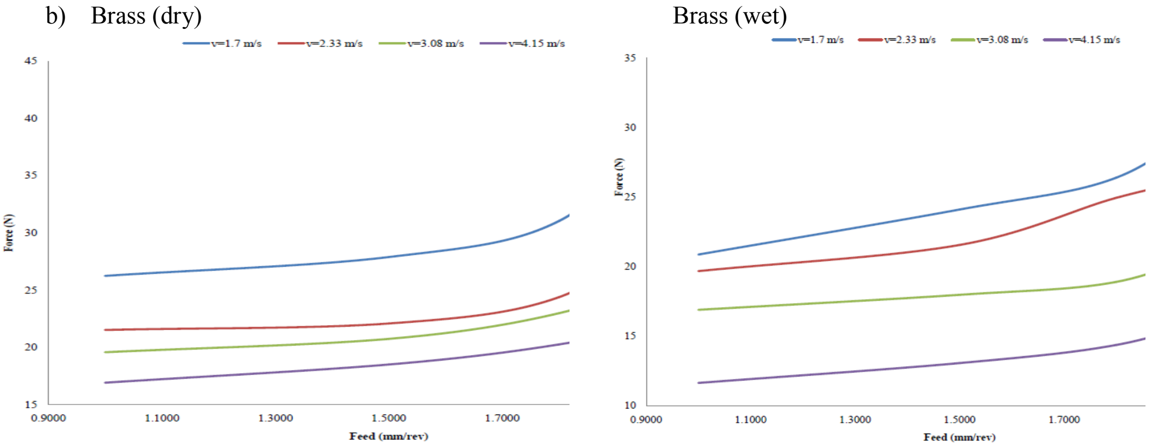
Mild steel (wet)

Fig 2b: Graph showing depth of cut against cutting force for Mild steel in both the dry and wet conditions



a) Aluminum (dry)

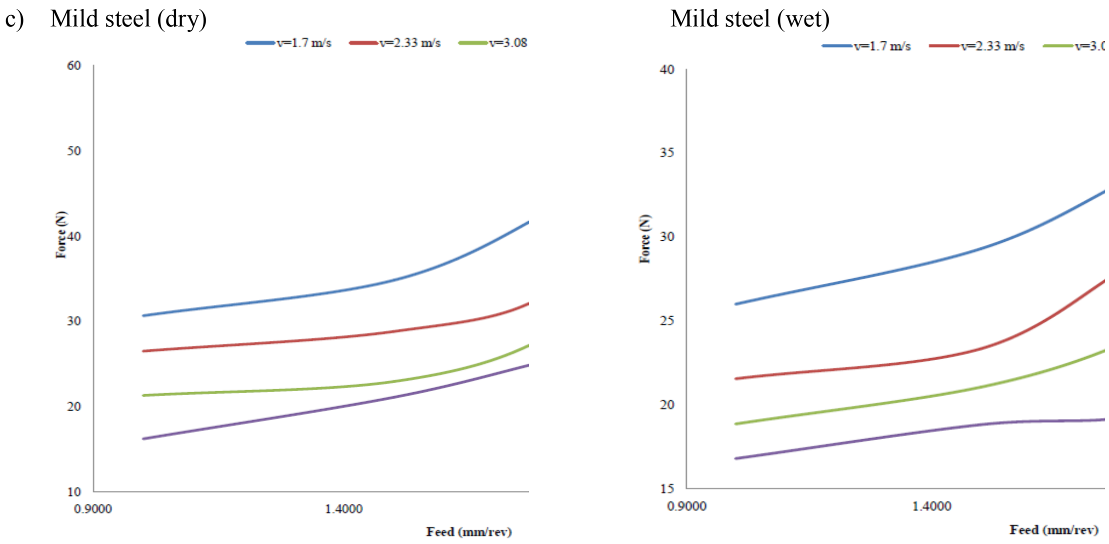
Aluminum (wet)



b) Brass (dry)

Brass (wet)

Fig 3: Graph of feed against cutting force for Aluminum and Brass in both dry and wet conditions


c) Mild steel (dry)

Mild steel (wet)

Fig 3b: Graph showing feed against cutting force for mild steel in both the dry and wet conditions

CONCLUSIONS

The study has established palm-kernel oil as a good metal cutting lubricant. Analysis of the three materials shown in Table 1 revealed that, varying turning parameters altered the performance of the lubricant in terms of the coefficient of friction. Hence, considering the range of parameters used for the experiment, aluminum reflected a good impact of lubrication with a reduction of 33.3% in coefficient of friction when rake angle was varied, while brass and mild steel show no effect of lubrication with 7.9 and 13.8 % increase in coefficient of friction. Similar work can be carried out with another range of parameters, especially in the lower range of values in order to establish the cutting condition under which the best machining quality could be achieved.

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