PERFORMANCE EVALUATION OF CASHEW NUT SHELL LIQUID AS A CUTTING FLUID

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ABSTRACT

Vegetable oil based cutting fluid developed from cashew nut shell liquid (CNSL) was used as a lubricant in the cutting operation of mild steel rod on a lathe machine with varying cutting speed, feed rates and depth of cut. The results were compared to that of other cutting fluids such as groundnut oil, palm oil and soluble oil (conventional). The parameters investigated were chip thickness ratio, surface temperature and cutting forces. Other parameters that were compared are viscosity values, corrosion rates and acidity. The performance of CNSL in this work when compared to soluble oil, groundnut oil and palm oil shows that it has good cutting fluid properties in the machining operation of mild steel. Amongst other things it can reduce surface temperature, chip thickness ratio and cutting forces which is due mainly to its high viscosity which is a major characteristic of most vegetable oils.

1. INTRODUCTION

Cutting fluids have been used extensively in metal cutting operations for the last 200 years. They are used to reduce the negative effects of heat and friction on both tool and work piece (Lopez *et al.*, 2006). They produce three positive effects in the process: heat removal, lubrication on the chip-tool interface and chip removal. As coolants, cutting fluids decrease the cutting temperature through heat dissipation. When water-based fluids are used, cooling is more important than lubrication. It is experimentally proven that cutting fluid efficiency decreases with increase in cutting speed and depth of cut (Shaw *et al.*, 1951).

In the past, vegetable oils have only traditional importance but today their industrial usefulness cannot be over-emphasized. Thus, the replacement of petroleum-based lubricants with those derived from vegetable oils is a worth-while step as this will reduce the dependence on non-renewable sources, reduction of greenhouse effects and increase in markets for agricultural products. A lot of research has been done in the development of vegetable oils as a substitute for petroleum-based lubricants. According to (Fox and Stachowjac, 2007), vegetable oils are chemically triglycerides of fatty acids. They are seen to possess excellent bio-degradability and lubricity, higher viscosity and viscosity index, enhanced flash and fire points and lower toxicity.

Vegetable oil with high stearic acid content is considered prime substitute for conventional mineral oil based lubricants because they are bio-degradable and non-toxic. They also have better intrinsic boundary lubricant properties because of the presence of long chain fatty acids in their chemical composition (Carcel and Palomares, 2004). Other advantages include very low volatility due to the high molecular weight of triglyceride molecule and excellent temperature viscosity properties.

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Their polar ester groups are able to adhere to metal surface and therefore possess good lubricating ability. They also show good lubricating abilities as they give rise to low coefficient of friction. However, many researchers report that although the coefficient of friction is low, the wear rate is high. This behaviour is possible due to the chemical attack on the surface by the fatty acid present in vegetable oil. The metallic soap film is rubbed away during sliding and produces the non-reactive detergents (Bowden and Tabor, 2001). The lubricity of vegetable oils is attributed to their ability to absorb the metallic surfaces and form a mono-layer with the polar head adhering to the metallic surface and the hydrocarbon chains orienting in near directions to the surface.

Vegetable oil based lubricants in general possess long polar fatty acid chains which provide high strength lubricant films that interact strongly with metallic surfaces and reduces both friction and were. They are also seen to possess some qualities such as excellent bio-degradability and lubricity, high viscosity and viscosity index, enhanced flash and fire points and lower toxicity. The cashew nut shell contains a viscous, dark liquid, known as CNSL, which is extremely caustic. Cashew nut consists of 35% to 45% of seeds and around 55% to 65% of shells as the CNSL content of the raw nut vary from 20 to 25 percent. CNSL is an important and versatile industrial raw material. There are more than 200 patents for its industrial application. The CNSL has diverse use in friction linings, paints and varnishes, laminating and epoxy resins and foundry chemicals. These industrial applications are based on the fact that it lends itself to polymerization by various means (Achal, 2002).

Lubricants penetrate the zone of contact between the tool and the freshly formed chip to impact friction (Srikant *et al*, 2009). The cutting edge of the operational tool is subjected to very demanding conditions, with contact stresses approaching three times that at room temperature, hardness of the work-piece and temperatures often exceeding 1000°C. During metal cutting operation, the material that is removed from the work piece slides along the rake face of the cutting tool in the form of continuous or discontinuous chips, resulting in friction.

In metal cutting operations, lots of heat is generated due to plastic deformation, friction at the rake face of the tool between the tool and the chip and also the friction between the work piece and the flank of the tool. This increases the temperature both of the work piece and the tool point resulting in decrease in hardness. The possibility of built-up edge also increases, making the use of cutting fluid during machining operation even more essential.

2. MATERIALS AND METHODS

2.1. MATERIALS USED

The materials used for this study includes the following; Lathe machine (Centre lathe with maximum spindle speed of 1000rev/min), cutting tool (High Speed Steel) with 10^0 rake angle, 9^0 clearance angle, 1.5mm nose radius and 10mm tool overhang, thermocouple with a temperature sensor, micrometre screw gauge, mild steel work pieces of 24mm diameter and 80mm long and cutting fluids which include; soluble oil (standard for mild steel), cashew nut shell liquid, groundnut oil and palm oil. The effects of groundnut oil, palm oil and cashew nut shell liquid on the chip thickness ratio, surface finish and surface temperature of the work piece at varying spindle speed, depth of cut and feed rate were investigated during the turning operation of mild steel on a centre lathe machine using a High Speed Steel (H.S.S) cutting tool. Soluble oil was used as a standard for comparison in the turning of mild steel. The experiments were carried out as follows using groundnut oil as the cutting fluid.

• Turning operations of mild steel at varying spindle speed (85, 112, 150, 200, 265, 300, 350, 420, 450, 480,540, 600, 635, 650, 680 rev/min); at a constant feed rate of 0.5mm/rev and constant depth of cut of 2mm.

• Turning operations of mild steel at varying depth of cut (1.0, 1.5, 2.0, 2.5,3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0mm); at a constant feed rate of 0.5 mm/rev and constant spindle speed of 180rev/min.

• Steps 1,2 and 3 above were repeated using palm oil and cashew nut shell liquid as the cutting fluid

• The experiments of step 1, 2, 3 were also repeated using soluble oil as a standard/ reference cutting fluid for mild steel.

For each turning operation that was carried out, the surface temperature, chip thickness were measured using the thermocouple and micrometre screw gauge respectively, while the corresponding chip thickness ratio and coefficient of friction computed using equation 1 and 2 respectively.

$$\lambda = \frac{t_1}{t_2} = \frac{uncut \cdot chip.tickness}{chip.thickness.aftercut} \quad (1)$$

where λ is the chip thickness ratio

$$\mu = \frac{In\lambda}{\frac{\pi}{2} - \alpha} \quad (2)$$

where μ is the coefficient of friction, λ is the chip thickness ratio and α is the rake angle. There is also a correlation between viscosity and temperature of lubricants. This is important to consider because liquid viscosities are sensitive to temperature and the range of temperature in which these correlations are valid is from 24^0C, (which is about the melting point of CNSL) to 110^0C. The correlation constants are significant parameters in the design of chemical process equipment.

3. RESULTS AND DISCUSSIONS

An organised set of procedures and guidelines were utilised for specifying the structural and quantitative parameters and how the CNSL behaves under set experimental conditions. This approach aids in evaluating the performance under these dynamic conditions. The key issues under consideration in the performance evaluation are how the change in operational condition affects the physiochemical behaviour of CNSL alongside other working (metal cutting) fluids. The operational conditions considered are the key mechanical inputs in metal working (removal operations) which include feed rate, speed and depth of cut. Manipulating these key parameters can maximise the benefits derived from a particular cutting fluid or lubricant and therefore can increase productivity.

Start of collection of data and experimental results were commenced after initial or transient conditions have faded. Such “warm-up” periods were necessary because they help ameliorate start-up and initialization biases.

The performance tests such as surface temperature, chip thickness ratio and coefficient of friction were carried out for CNSL. The values generated were juxtaposed with that from the other cutting fluids. Table 1 below shows the effect of varying spindle speed on the turning of mild steel and the effect of varying depth of cut on the turning of mild steel for soluble oil.

Table 1: Effect of varying spindle speed on the turning of mild steel at constant depth of cut of 2mm for soluble oil

Lubricant	Speed (rev/min)	Chip thickness (mm)	Chip thickness ratio (λ)	Surface Temperature (°C)	Coefficient of friction (μ)
Soluble oil	85	0.6800	0.3400	31	0.1280
	150	0.6700	0.3350	38	0.1297
	300	0.5300	0.2650	44	0.1640
	450	0.6500	0.3250	50	0.1333
	540	0.5800	0.2900	56	0.1469
	680	0.7000	0.3500	68	0.1245

In a like manner, table 2 displays output performance values of varying spindle speed on the turning of mild steel and the effect of varying depth of cut on the turning of mild steel for CNSL. These values follow similar pattern with that of other cooling fluids under examination.

Table 2: Effect of varying spindle speed on the turning of mild steel at constant depth of cut of 2mm for CNSL

Lubricant	Speed (rev/min)	Chip thickness (mm)	Chip thickness ratio (λ)	Surface Temperature (°C)	Coefficient of friction (μ)
CNSL	85	0.5800	0.1400	45	0.2333
	150	0.6400	0.3200	52	0.1352
	300	0.5200	0.2600	63	0.1598
	450	0.5400	0.2700	70	0.1553
	540	0.5700	0.2850	73	0.1489
	680	0.6500	0.3250	82	0.1333

The set of operations were repeated, but this time with groundnut oil. The experimental results are included on Table 3, observing how the values obtained show striking similarity.

Table 3: Effect of varying spindle speed on the turning of mild steel at constant depth of cut of 2mm for groundnut oil

Lubricant	Speed (rev/min)	Chip thickness (mm)	Chip thickness ratio (λ)	Surface Temperature (°C)	Coefficient of friction (μ)
Groundnut oil	85	0.7000	0.3500	46	0.1245
	150	0.8400	0.4200	54	0.1058
	300	0.6000	0.3000	60	0.1428
	450	0.6800	0.3400	72	0.1230
	540	0.6300	0.3150	78	0.1370
	680	0.7800	0.3900	88	0.1117

Finally, the values obtained from using palm oil in place of the other fluids have been included in table 4. As usual the spindle speed is varied at constant depth of cut of 2mm.

Table 4: Effect of varying spindle speed on the turning of mild steel at constant depth of cut of 2mm for palm oil

Lubricant	Speed (rev/min)	Chip thickness (mm)	Chip thickness ratio (λ)	Surface Temperature (°C)	Coefficient of friction (μ)
Palm oil	85	0.5400	0.2700	66	0.1553
	150	0.4000	0.2000	118	0.1909
	300	0.7200	0.3600	80	0.1212
	450	0.4800	0.2400	84	0.1693
	540	0.6000	0.3000	88	0.1428
	680	0.700	0.3500	88	0.1245

Plots for different behavioural patterns of these conventional lubricants/fluids (soluble oil, groundnut oil and palm oil), compared with CNSL have been shown below.

Figure 1 shows the plot of chip thickness ratio against spindle speed. Chip thickness ratio could be the change of thickness as the chip material is being removed. However, depending on cutting tool geometry and material properties, the chip will be thicker or thinner than the depth of cut. From the figure, chip thickness is low for soluble oil but high for groundnut oil followed closely by CNSL.

There is also slight increase in chip thickness ratio with increasing speed, and a decrease as the speed increases at constant depth of cut. On a more general note, chips become thinner with application of cutting fluids. Better lubricants give rise to higher reduction in chip compression with higher speed. (Leyesenter and In'Kroneburg, 1966) saw that for an increase in cutting speed, there is a corresponding decrease in chip thickness. (Rosenberg and Yeremin, 1973) found that at low cutting speeds, there is absence of built-up edge as only a discontinuous chip is produced and a low surface temperature. Increase in cutting speed produces continuous and inhomogeneous chips.

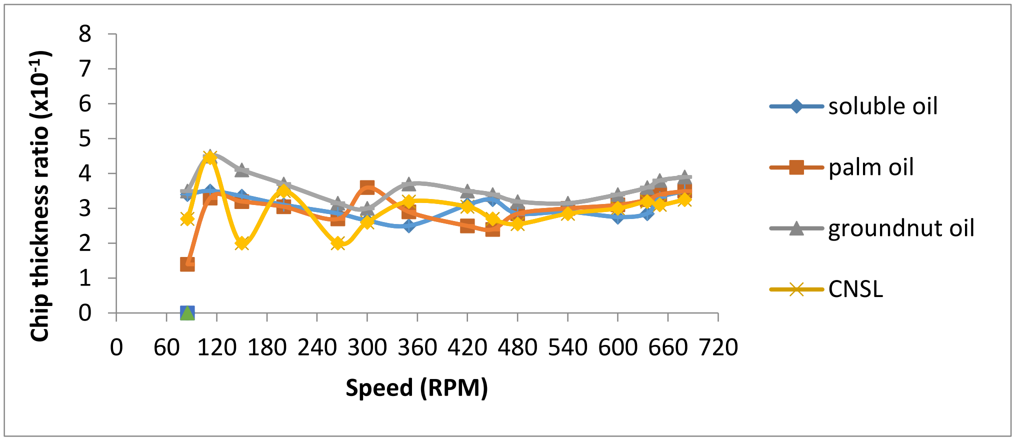

Figure 1: Effect of spindle speed on the chip thickness ratio for mild steel at constant depth of cut of 2mm

In a like manner, Figure 2 plots the graph of chip thickness ratio against the depth of cut. It shows that as depth of cut (which is measurement of how wide and deep the tool cuts into the work-piece) increases, there is corresponding decrease in the chip thickness ratio. This is because chip thickness ratio is dependent on depth of cut and uncut chip thickness. The variation in chip thickness ratio is due to the changing values of the actual cutting angle, formation of built up edge and variation in coefficient of friction. The reduction of chip thickness ratio with depth of cut was investigated by previous authors (Arshinov and Alekseev, 1973). There was a sharp increase in chip thickness ratio for groundnut oil beyond depth of cut of 5.5mm while other fluids continued a downward pattern.

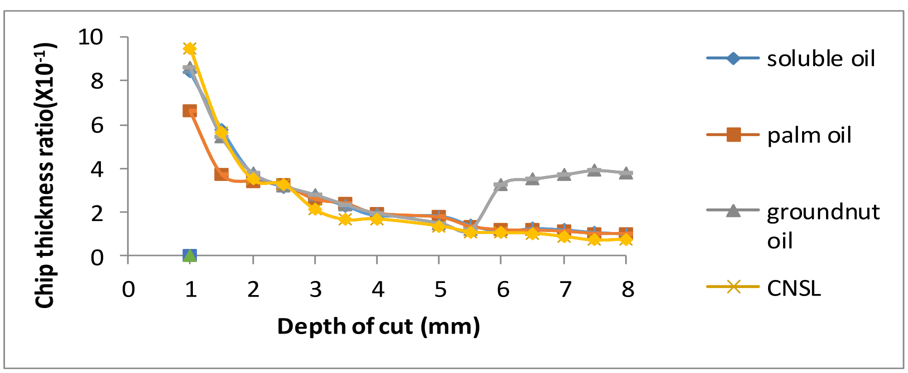

Figure 2: Effect of depth of cut on the chip thickness ratio for mild steel at a constant speed of 150rev/min

Figure 3 deals with the plot of graph of coefficient of friction against speed. The relationship between the coefficient of friction, μ, the chip thickness ratio, λ, and rake angle, α, has been shown mathematically in equations 1 and 2. If the thickness of the removed material is equal to the depth of cut (and sometimes it is), the chip thickness ratio is 1.0. The chip will be thicker or thinner than the depth of cut, due to deformation of the chip as it is removed.

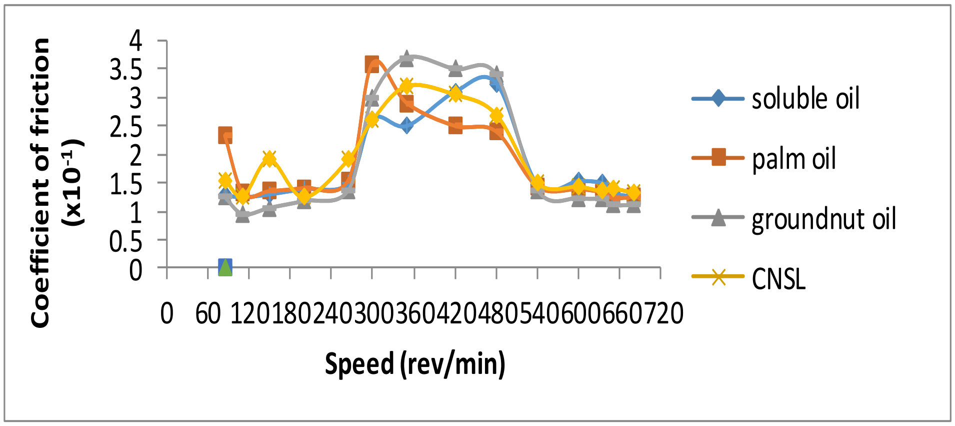

Figure 3: Effect of varying speed on the coefficient of friction for mild steel at a constant depth of cut of 2mm.

Figure 4 shows the graph of coefficient of friction against depth of cut. An increase in depth of cut is followed closely by corresponding increase in the coefficient of friction in (figure 4). From equation 2, coefficient of friction is dependent on the chip thickness ratio which in turn depends on the depth of cut. It is seen that as depth of cut increases, the coefficient of friction also increases. Recall that coefficient of friction has value between 0 and 1, and is a ratio of the mechanical force causing a body to slide and the force. From the figure, groundnut oil and soluble oil deviated slightly at depth of cut of 5mm. However, soluble oil recovered at 5.5mm and resumed the upward trend of coefficient of friction commensurate with increase in depth of cut. Groundnut oil also continued a downward pattern of coefficient of friction with increase in depth of cut.

The plot of temperature against speed is displayed in figure 5. The surface temperature also increases for all lubricants. While there was gradual increment in temperature with adjustment in speed, CNSL peaked at 120^{0}C for just a small increase in speed and drops again as beyond 148revs/min.

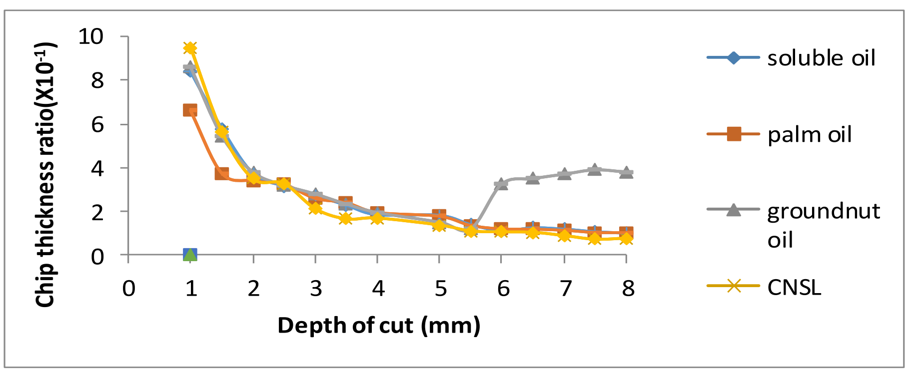

Figure 4: Effect of varying depth of cut on the coefficient of friction for mild steel at a constant speed of 150rev/min.

At low cutting speeds, the deformation at the shear zone affects the tool-chip region temperature, which is the most important variable for the tool-chip temperature. Soluble oil performed better than the rest of the vegetable oils in terms of temperature reduction which may be as a result of the large volumes of water which cools the work piece/ tool interface. This is because water reduces the working temperature for mild steel during machining by about 20% (Arshinov and Alekseev, 1973). (Obi *et al*, 2001) Confirmed the effects of temperature of the local lubricants on the turning of mild steel and revealed that temperature increases with the speed of turning; which is also verified in this work. Cooling effects (heat reduction ability) follows thus in increasing order: CNSL, palm oil, groundnut oil and soluble oil.

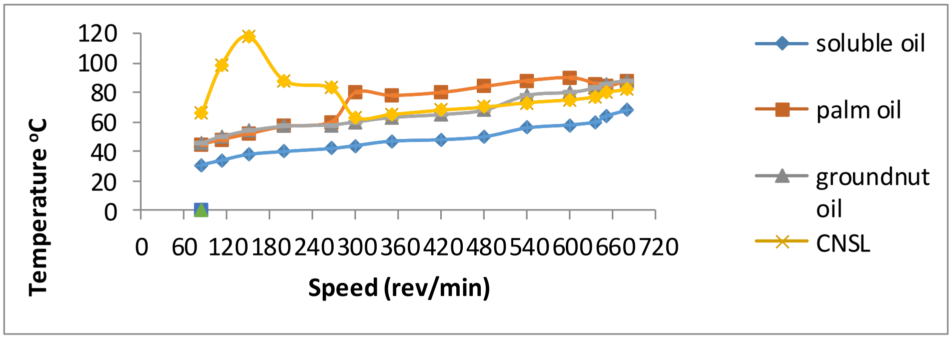

Figure 5: The effect of varying speed on the temperature for mild steel at a constant depth of cut of 2mm

Temperature is plotted against depth of cut in figure 6. It is seen that as the depth of cut increases, the surface temperature also increases for soluble oil, palm oil as well as groundnut oil. With the CNSL, there was sharp increase in surface temperature with increase in depth of cut to 2mm. The increasing temperature with increasing depth of cut is due to increasing cutting forces with depth of cut leading to high tool wear and hence high temperatures. Though the upwards trend for CNSL temperature versus depth of cut plot was not sustained and it falls with no particular pattern. The properties of vegetable oils which enhance their performance during metal cutting operation include the presence of fatty acids (Ajala, 1998). These fatty acids are effective as boundary lubricants due to chemical reaction between polar head of the acid molecule and the surface they react with to produce the absorbed layer which is sufficiently thick to separate the surface completely, thereby reducing friction (Rowe, 1978).

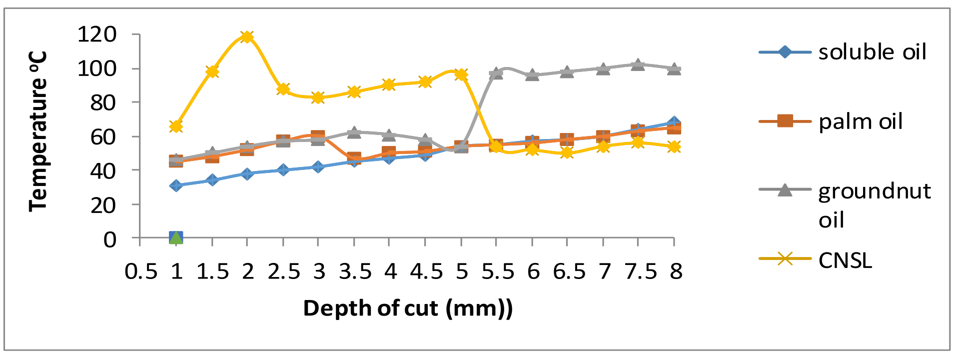

Figure 6: The effect of depth of cut on the temperature for mild steel at a constant speed of 150rev/min

4. CONCLUSION

The structural and behavioural performance of CNSL has been investigated side by side with other established conventional cutting fluids in this research. Different output performance plots captured through manipulating the three key mechanical inputs in metal removal/ cutting operations (cutting speed, feed rate and depth of cut) show how the behaviour of CNSL is not far from that of other existing vegetable oil lubricants. From the results it is shown to be a viable substitute for these conventional cutting fluids.

Overall it can be safely concluded that Cashew Nut Shell Liquid can be a prime candidate to be used as a reliable alternative to replace petroleum-based lubricants. Thus, adding yet another vegetable oil to existing list of metal-working lubricants and reducing reliance on petroleum and mineral-based alternatives with emphasis on reduction of greenhouse effects and increase in market for agricultural products.

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