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Comparative Study of Lubricity of Mixed Coconut/Diesel Oil and Neem Seed Oil in Cold Rolling of Aluminum Alloy

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Abstract

Performance of mixed coconut/diesel oil (factory rolling oil) and neem seed oil as lubricants for friction reduction in cold rolling of 8011 commercial aluminum alloy has been investigated using plane strain compression test. The proportions of mixture of coconut oil and diesel as lubricant to ascertain the ratio which gives the highest percentage reduction in thickness was also investigated. A total of ten plates, each of dimension 240mm x 40mm x 7mm, were compressed with five different loads ranging from 80kN to 120kN. Mixed coconut/diesel oil served as lubricant in cold compression of the first five plates while neem seed oil was used for the remaining five plates. Locally sourced coconut oil and diesel were mixed in five different proportions and each of the oil mixture was used as lubricant in compressing aluminum alloy of dimensions 140mm x 40mm x 4.9mm at 100kN load. The results showed that at the lowest reduction load of 80kN, the reduction in thickness of 6.15% and 4.14% were respectively obtained under neem seed oil and coconut/diesel oil lubricants while 48.47% and 34.57% respectively were obtained at the highest load of 120kN. These results showed that neem seed oil performed better than mixed coconut/diesel oil at any specific load and the difference in performance was more pronounced at higher loads. The mixture of locally sourced coconut oil and diesel in various proportions performed best as friction reducer at 70% diesel and 30% coconut oil.

Keywords: Coconut oil, deformation, diesel, neem seed oil.

1.0 Introduction

The importance of metal in modern technology is due, in large part, to the ease with which they may be formed into useful shapes such as tubes, rods and sheets (Dieter, 1988). Most of these useful shapes are formed by plastic deformation processes such as rolling, wire drawing, extrusion and these are carried out at a relatively high strain rates. However, strains and strain rates are not uniform through the section (Colas & Sellars, 1987); therefore the friction effect between the surfaces in contact results in localized variations in temperature changes during the deformation. Such localized variations are of importance because of the relationship between the deformation and the resulting microstructure.

The rolling process always results in a very heterogeneous deformation across the thickness of the slab, which in turn implies the development of a gradient of deformation textures (Boldetti *et al.,* 2006). This heterogeneity of deformation and texture affect the final rolled sheet leading to well-known industrial problems such as edge cracking and earing (Boldetti *et al.,* 2006). To help overcome this, the study of friction and lubrication become essential in metalworking processes.

Friction and lubrication in sheet metal forming are influenced by such parameters as material properties, surface finish, temperature, sliding velocity, contact pressure, and lubricant characteristics (Tekkaya & Altan, 2012). Depending on these parameters, the performance of a lubricant and the coefficient of friction vary. Material flow in the die cavity is influenced by frictional conditions at the die/work-piece interface (Tekkaya & Altan, 2012). Therefore, good understandings of the lubricant used in friction reduction for production of good-quality sheet metal parts become paramount. In sheet metal forming, the magnitude and distribution of friction affect metal flow, part defects, and quality, as well as tool wear and production costs (Tekkaya & Altan, 2012).

Friction also plays an important role in metalworking process. The most obvious effect of friction in general is that work has to be expended which would have otherwise not been necessary. The higher the friction, the greater the load required to produce a particular deformation (John, 1991). Friction is however advantageous in some aspects. In rolling of a flat strip, the rolls will skid if the friction is too low, and it is necessary to use a relatively poor lubricant to obtain the greatest possible reduction per pass (Atkins, 1974). Effective lubrication systems result in low friction levels which reduce the loads imposed on tooling and work-piece (John, 1991) as well as other metalworking defects. This can eliminate the problem of tooling or work-piece failures or permit a reduction in the number of steps required to form a part.

1.1 Chemical Composition of Lubricating Oils

Fatty oils are polar substances having very long carbon chains with one or more chemically active or polar groups at one end. Both the chemical and physical properties of the oil are determined by their fatty acid radicals which may contain some saturated (unreactive) and unsaturated (reactive) acids. The unsaturated fatty acids are the polar groups that adhere strongly to the work piece and tool surfaces, causing long chain to be oriented at approximately right angles to the metal surfaces (Babaagba, 1986). These oriented films of polar substances, which are several molecules thick, minimize metal-to-metal contact and friction thereby reducing wear. The relative amount of the polar substances in fatty oils has been found to be a measure of degree of unsaturated fatty acids in the oil (Babaagba, 1986).

The saturated fatty acid contents of local oils are caproic, caprylic, capric, lauric, myristic, palmitic, stearic, arachidic, behenic, linoceric acids etc (Lugt *et al.,* 1993). However, with the presence of carboxylic groups, these acids help in maintaining a strong molecular adherence of the fatty oils to metal surface thereby minimizing friction. The unsaturated fatty acid contents are the oleic and linoleic acids (Lugt *et al.,* 1993). These acids by themselves are reactive in addition to the presence of carboxylic groups. They therefore contribute more to the molecular adherence of the oils onto the metal surfaces. Ordinary mineral oils like paraffin do not have this polar (reactive) group because they are saturated molecules (having chain structure).

Dave (1995) stated that polar groups such as C_{12}-C_{18} saturated fatty acids or alcohol provide better boundary lubrication when the fluid film are too thin to provide hydrodynamic lubrication. He also affirmed that the fatty acids tend to be more effective since they can react with oxides surfaces on the metal to form soap. Saponification value of rolling oil directly affects its lubricating property. The higher the saponification value the better the lubrication property of the oils as opined by Dave (1995).

1.2 Modes of Lubrication in Cold Rolling

In industrial metalworking, there are two basic modes by which lubricants decrease friction (Atkins, 1974). These are hydrodynamic and boundary lubrications.

1.2.1 **Hydrodynamic Lubrication**

In hydrodynamic mode of lubrication, reduction in friction is achieved by maintaining a constant fluid film between solid surfaces. When fully separated, the resistance to motion is only due to the interposed fluid layer. The lubricity of this fluid depends on the area of the film, the rate of shear and the viscosity of the lubricant (Lugt *et al.,* 1993).

1.2.2 Boundary Lubrication

In boundary lubrication, metal to metal contact inevitably occurs. Boundary lubrication typically has a higher coefficient of friction and does allow wear to occur, although it is greatly reduced.

As in most metal working processes, the main reason for the use of lubricant in the cold rolling process is to control friction and surface quality. Under most circumstances, steel and aluminum are lubricated in such a way that asperities will touch and carry part of the load, causing additional friction (Lugt *et al.,* 1993). If the rubbing surfaces are completely separated by a lubricating film, "hydrodynamic pits" may be formed, resulting in a dull surface, whereas if the lubrication mechanism is of mixed type (hydrodynamic and boundary), the bright surface of the rolls is printed on the strip (Atkins, 1974).

In the mixed lubrication situation, friction is caused by both viscous shear in the lubricating film and shear between the touching asperities. Low friction reduces the rolling force, which again reduces the elastic flattening of the work rolls and enables a larger reduction with reduce cracking defect. However, if the friction is too low the rolls will skid and the strip will no longer be drawn through the rolls bite (Atkins, 1974).

1.3 Evaluation of Lubricants in Cold Rolling by Plane Strain Compression Test

Before oil can be used as a lubricant in metalworking operation, a thorough evaluation of its performance characteristics is necessary. Without a good knowledge of the effective performance of lubricants being used, it is often impossible to assess the efficiency of the metalworking processes. John (1991) enumerated a number of attributes of metalworking lubricants some of which include controlled friction, reduced wear, avoidance of metal pickup on the surface, cooling, protection of old and new surfaces, compatibility with die and work-piece, durability of lubricant film, rapid response, controlled stability and harmless residues.

In the assessment of any lubricant, it is therefore necessary to carry out laboratory tests which duplicate as closely as possible the conditions found in commercial metalworking operations. It is for this reason that the plane strain compression test also known as Watts-Ford test, is usually used to simulate material behavior in thermo mechanical processes such as rolling (Sutcliffe *et al.,* 2002).

In plane strain compression test, a flat strip is compressed between flat parallel platens where the strip is thin compared with the width of the tool; deformation is approximately homogenous in the bite. As long as the width of the strip is large compared with the thickness of the tool, spread is small and plane strain conditions apply (Sutcliffe *et al.,* 2002). These conditions are similar to those prevailing in cold metal rolling, justifying the use of such test to model rolling process. The dimensions of the specimen and the tool must satisfy the following inequality conditions;

$w > 5h$ and $b > 2h$ to $4h$

where w is width of the strip, h is thickness of the strip and b is the tool thickness (Rowe, 1968)

The reduction capacities of the oils are being investigated based on the reduction in thickness of the material obtained after the test. A schematic diagram of the plane strain compression test is shown in Figure 1.

$$\% \text{ thickness reduction} = \frac{\text{Initial thickness} - \text{Final thickness}}{\text{Initial thickness}} \times 100\% \quad (1)$$

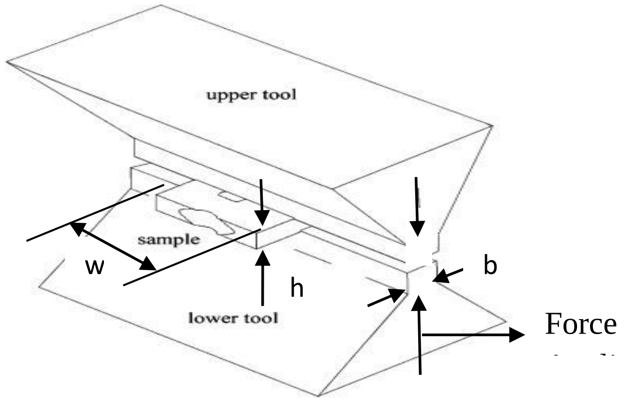

Fig. 1: A schematic diagram of the plane strain compression test set-up (Boldetti *et al.,* 2006).

The present investigation aimed to compare the lubricity potential of mixed coconut/diesel oil being used commercially as factory rolling oil in cold rolling operation of aluminum alloy 8011 (AA 8011) with already established neem seed oil lubricant using the same alloy and also to determine the optimum ratio of mixture of coconut oil and diesel with regard to friction reduction in cold rolling operation of the aluminum alloy.

2.0 Materials and Method

2.1 Chemical Analysis of the Investigated Oils and AA 8011

The mixed coconut/diesel oil and neem seed oil used for this research work were obtained from Tower Aluminum Rolling Mills, Ota, Ogun State and National Research Institute for Chemical Technology (NARICT), Zaria, respectively. Mixed coconut/diesel oil is the standard metalworking lubricant used in Tower Aluminum Rolling Mills in cold rolling of aluminum alloys, and throughout this work, mixed coconut/diesel oil refers to this factory oil. The analyses of the oils were conducted using Gas Chromatography Mass Spectroscopy (GCMS) available at NARICT, Zaria. The free fatty acids and the saponification values of the two oils were determined using equipment (titration apparatus) available in Chemical Engineering Department, Ahmadu Bello University, Zaria. Formulation of an alternative lubricant (mixing of coconut oil and diesel in various proportions) was achieved with the aid of facilities (measuring glass cylinders) provided in Biochemistry Department, Ahmadu Bello University, Zaria. Five different proportions of the mixtures were prepared for the analysis. The commercial aluminum alloy 8011 in form of plate was received from Tower Aluminum Rolling Mills and the compositional analysis of the alloy was conducted in the same company using Optical Emission Spectrometer (OES) and the result is shown in Table 1.

Table 1: Chemical composition of commercial aluminum alloy 8011.

Elements	Al	Fe	Si	Mn	Cu	Mg	Ti	Zn	Cr	Pb
Composition (%)	98.183	0.857	0.551	0.117	0.072	0.020	0.015	0.120	0.050	0.015

2.2 Plane Strain Compression Test

The performance of mixed coconut/diesel oil and neem seed oil as cold rolling lubricants for as-received AA 8011 was carried out by plain strain compression test. The test was conducted on Universal Compression Testing Machine according to ASTM E9 standard. (ASTM standard has no date). The platen used was 18mm in thickness. A total of ten plates (five plates for compression test under mixed coconut/diesel oil lubrication and five plates under neem seed oil lubrication) of dimensions 240mm x 40mm x 7mm each were used for the experiment. The surfaces of the plates and platens of compressive testing machine were cleaned with a mixture of methanol and ethanol using cotton wool. Each of the oils under investigation was applied to the surface of both the plates and the platens. The test on individual oil consists of compressing the plate between the platens with a load of 80kN, 90kN, 100kN, 110kN and 120kN accordingly by taking five impressions on each plate, after which the resultant reductions in thickness were measured using a Vernier caliper.

The evaluation of the mixture of coconut oil and diesel was carried out by compressing another five samples of the aluminum alloy of dimension 140 x 40 x 4.9 mm on a universal compression testing machine with a load of 100kN by taking five impressions for each sample using each proportion of oil mixture as lubricant (20%C80%D, 25%C75%D, 30%C70%D, 35%C65%D and 40%C60%D) where C and D represent coconut oil and diesel respectively. The resultant reductions in thickness after compression were measured accordingly. The variation in thickness is assumed to be related to frictional condition produced by the lubricants (Watts and Ford, 1952). The percentage reductions in thickness were determined using Equation 1.

3.0 Results and Discussion

3.1 Chemical Analysis of the Investigated Oils

The fatty acid composition of the individual oils under investigation and their saponification values and percentage free fatty acid are presented in Tables 2 and 3 respectively.

Table 2: Fatty acids composition of the oils

Type	Chain length	Double bond	Neem seed oil	Mixed coconut/diesel oil
Myristic	14	0	1.33	-
Palmitic	16	0	17.21	-
Stearic	18	0	15.23	-
Oleic	18	1	49.46	1.38
Linoleic	18	2	16.77	-
Percentage un-saturation			66.23	1.38

The disparities between neem seed oil and coconut/diesel oil and how it affects their performance as lubricant in cold rolling operation had been extensively discussed under Figure 2 below

Table 3: Saponification value and free fatty acid of the oils

Lubricating oil	Saponification value ($mgKOHg^{-1}$)	Free fatty acid (%)
Neem seed oil	180.92	23.12
Mixed coconut/diesel oil	25.25	4.23

3.2 Lubricity Capacity of mixed Coconut/Diesel and Neem Seed Oils in Cold Rolling Process

In metalworking industries, friction is control by applying lubricant to the contact surfaces. Most industries mixed liquid oils to form the lubricant in order to achieve effective lubrication due to the combined properties of the two oils. It is also effective to use single oil for better lubrication because some desire properties of the mixed oil may have been distorted or the optimum level at which the oil will have the best lubricity may be difficult to ascertain. The results obtained after plain strain compression test of aluminum alloy lubricated by mixed coconut/diesel oil and neem seed oil are shown in Fig. 2.

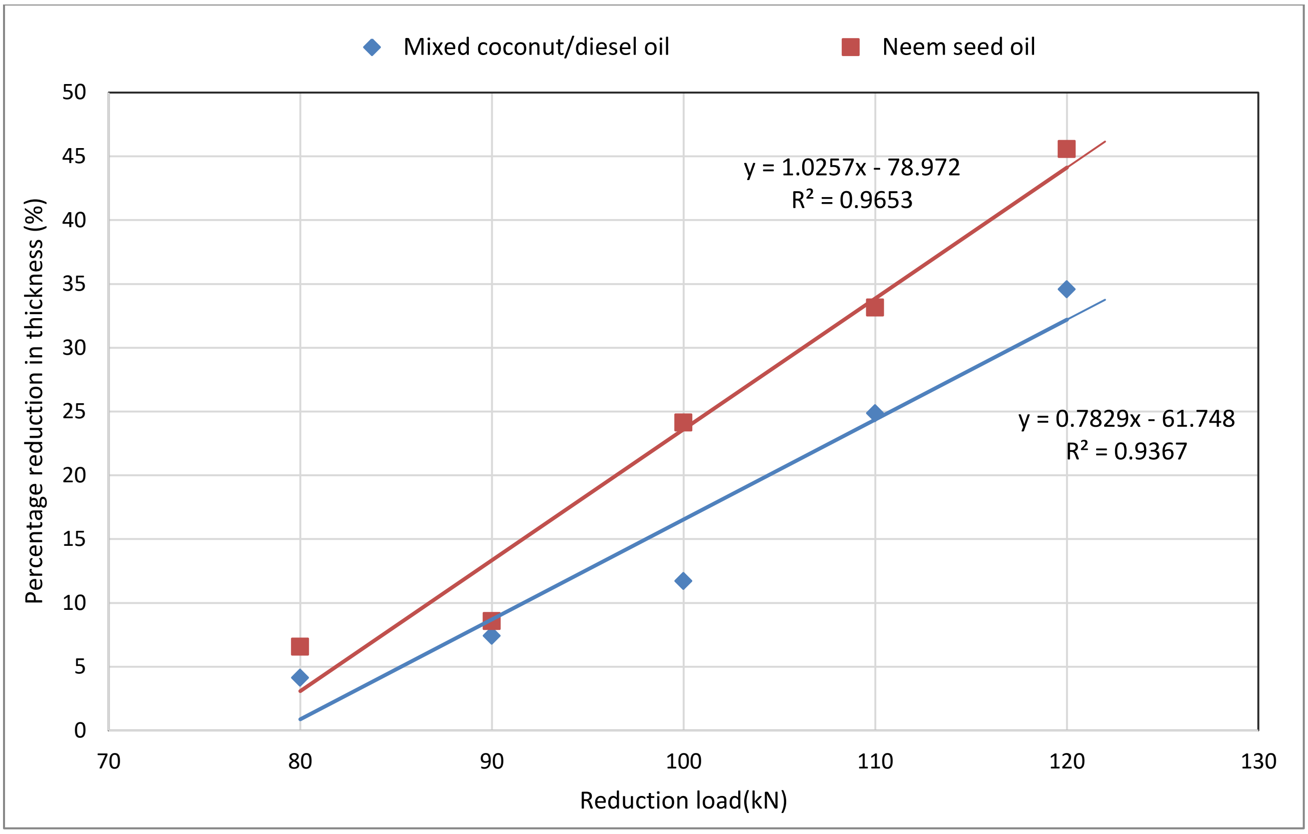

Fig. 2: Reduction capacity of the mixed coconut/diesel and neem seed oils.

From the plot of percent reduction in thickness against reduction load (Fig.2), it was obvious that neem seed oil performed better than mixed coconut/diesel oil at any specific load and the difference in performance becomes wider at higher loads. The regression equations of neem seed oil is

$$y = 1.0257x - 78.972 \tag{2}$$

and mixed coconut/diesel oil is

$$y = 0.7829x - 61.748 \tag{3}$$

where y = reduction in thickness (%)

x = reduction load (kN).

It can be deduced from the equations that at the reduction loads of say 100kN and 120kN, neem seed oil gives reduction in thickness of 23.60% and 44.11% while mixed coconut/diesel oil gives 16.54% and 32.20% respectively and this justified the best performance shown by neem seed oil over mixed coconut/diesel oil stated earlier. The coefficient of determination, R^2 of neem seed oil and mixed coconut/diesel oil are 96.53% and 93.67% respectively. The higher values of R^2 obtained indicates that the models are reliable in prediction of percentage reduction in thickness at any particular reduction load used in cold rolling of AA 8011 using mixed coconut/diesel oil or neem seed oil as lubricant.

The reasons for the above observations are due to the fatty acids content and saponification values of the oils under investigation. The result of Gas Chromatography Mass Spectroscopy shown in Table 2 revealed the presence of oleic acid as the only fatty acid present in mixed coconut/diesel oil whereas myristic, palmitic, stearic, oleic and linoleic acids were found in neem seed oil. Accordance to Babaagba (1986), the carboxylic groups of the fatty acids molecules oriented themselves with the metal surfaces which results in the formation of a film of fatty acid molecules on the metal surfaces. These film layers actually isolate the surface forces of the metal from the work rolls depending on the chain length of the fatty acid, and the friction is substantially reduced leading to higher deformation when neem seed oil was used as lubricant. Long straight hydrocarbons which are the major components of mixed coconut/diesel oil are saturated compounds which contain no polar group to enhance friction reduction. This accounted for low values of deformation obtained when mixed coconut/diesel oil was used as lubricant.

The higher percentage of unsaturated fatty acids (oleic-49.46% and linoleic-16.77%) in neem seed oil compared to only oleic acid (1.38%) in mixed coconut/diesel oil could have also contributed to better performance obtained under neem seed oil lubrication. This is due to their high affinity to react and adhere strongly to the work-piece and tools surfaces, causing long chain to be oriented approximately at right angles to the metal surface thereby minimizing metal-to-metal contact and hence friction is reduced.

Fatty acids tend to be more effective in friction reduction because of their ability to react with active oxide surface of the metal to form soap (Dave, 1995). The ease with which oil can form soap in mechanical working operation helps in minimizing friction by the formation of adherent layer which separate the work-piece from the tool. This implies that lubricity of any oil also depends on its saponification value which indicates the ease with which the oil forms soap. Neem seed oil has a saponification value of 180.92 mgKOHg^{-1} compared to mixed coconut/diesel oil with a value of 25.25 mgKOHg^{-1}. This may be responsible for low performance observed in mixed coconut/diesel oil when used as lubricant.

3.3 Lubricity Capacity of Mixture of Coconut and Diesel Oils in Cold Rolling Process

The fatty acids content of the oils provide little information regard to their effectiveness when mixed to form lubricant. The determination of the proportion of the mixture for effective lubrication by mixing two oils together at different ratios and then subject each ratio to mechanical deformation reveals vital information of the lubricant. The result of Gas Chromatography Mass Spectroscopy revealed oleic acid (1.38%) as the only fatty acid present in the mixed coconut/diesel oil. Finding into the optimum proportion of mixture of these two oils that will enhance the highest friction reduction in cold rolling of AA 8011 was then investigated and the results displayed in Fig. 3.

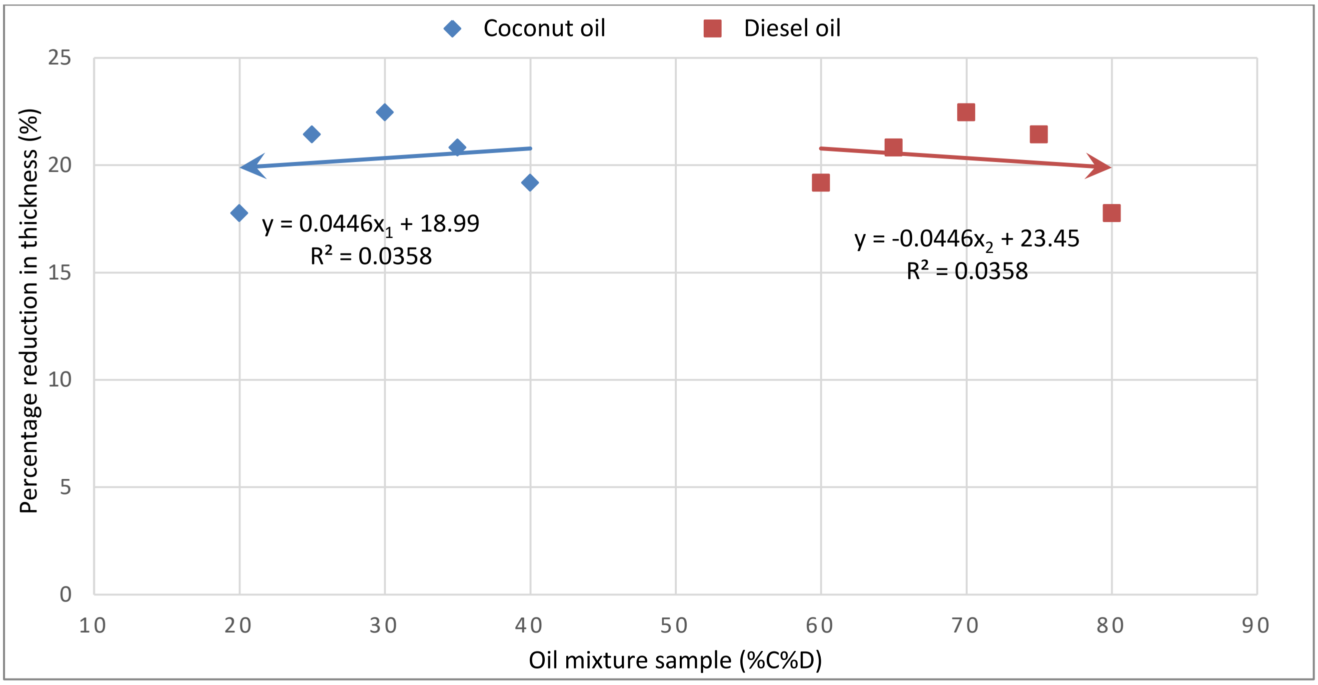

Figure 3: Reduction capacity of the locally sourced coconut oil mixed with diesel in various proportions

As shown in Fig. 3, the mixture of the oils gives the highest percentage reduction in thickness at 30%C70%D at a reduction load of 100kN load. The regression equations of mixture of coconut oil and diesel are respectively

$$y = 0.0446x_1 + 18.99 \quad (4)$$

and

$$y = -0.0446x_2 + 23.45 \quad (5)$$

where y = reduction in thickness (%)

x_1 and x_2 = percentages of coconut oil and diesel in the mixture respectively (%).

From Fig. 3, at a mixed ratio of 30%C70%D, the reduction in thickness of 22.45% was obtained which is higher than 21.43% and 20.82% when the mixed ratios were 25%C75%D and 35%C65%D respectively. The low value of coefficient of determination, R^2 (3.58%) obtained showed that the linear equations are not reliable in predicting the percentage reduction in thickness of cold-rolled AA 8011 under mixture of coconut oil and diesel lubricant.

The level of wettability and lubricity of the lubricant could be responsible for this observation. The coconut oil mainly provided the lubricity to the lubricant while diesel supplied the wetting action. According to Peter *et al.* (2011), the formulations of straight oils lubricants contain no water and are comprised of petroleum and/or vegetable oils. Animal, marine, or vegetable oils may also be used singly or in combination with mineral oils to increase wetting action (Peter *et al.,* 2011) of the lubricant.

As observed in Fig. 3, the percentage reduction in thickness of the material increase as more coconut oil are being introduced in to the mixture and reaches peak level at 30% coconut oil and 70% diesel. This could be due to high level of wettability and lubricity of the lubricant caused by moderate percentages of coconut oil and diesel in the mixture. At the peak level, the lubricant became warmth giving rise to highest potential for friction reduction. As more coconut oil was being introduced, the reaction of the lubricant with the metal surface became lower due to the cooling effect of the lubricant caused by higher level of coconut oil in the mixture and this resulted in reduction in lubricity which accounted for gradual drops in percentage reduction in thickness.

4.0 Conclusions

Based on the experimental findings, it can be deduced that at any particular deformation and reduction load considered, neem seed oil performed better than mixed coconut/diesel oil in friction reduction of cold-rolled AA 8011. At any value of reduction load used in deforming AA 8011 under mixed coconut/diesel oil or neem seed oil lubricant, the percentage reduction in thickness can be predicted from the equations; $y = 0.7829x - 61.748$ for mixed coconut/diesel oil and $y = 1.0257x - 78.972$ for neem seed oil.

The optimum ratios of mixing coconut oil and diesel that will enhance the highest friction reduction in cold rolling of AA 8011 are respectively 30% and 70% when deforming at 100 kN load. In cold rolling of AA 8011 using mixture of coconut oil and diesel as lubricant, the percentage reduction in thickness is linearly related to the proportion of the mixture by the following equations; $y = 0.0446x_1 + 18.99$ and $y = -0.0446x_2 + 23.45$, for coconut oil and diesel respectively.

That mixture of mineral oil and vegetable oil to form lubricant has greater advantage of improving the wettability but care must be taken in order not to exceed the optimum ratio of the mixture as there may be drastic decrease in lubricity.

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References

Atkins, A. G. (1974). Hydrodynamic lubrication in cold rolling, *International Journal of Mechanical Science,* Pergamon Press, Great Britain, 16, 1-19.

Babaagba, R. S. (1986). Evaluation of local oils as lubricants in deep drawing operations. M.Sc. Thesis, Ahmadu Bello University, Zaria, Nigeria

Boldetti, C., Pinna, C. & Howard, C. (2006). Measurement and prediction in plane strain compression tests of AA 5182. *Journal of Material Science and Technology,* 22(11), 1380-1386.

Dave, P. (1995). Industrial lubrications cleaning and waste minimization, *Precision Cleaning Proceeding*. 208-216

Dieter, G. E. (1988). *Mechanical metallurgy.* SI Metric Edition, London: McGraw-Hill Book Company. 587.

John, A. S. (1991). *Metal deformation processes/friction and lubrication,* New York: Marcel Dekker Inc. 242.

Lugt, P. M., Wemekamp, A. W. & W. E. Napel, (1993). Lubrication in cold rolling; elato-plasto-hydrodynamic lubrication of smooth surface, *Hoogovens Research Laboratory,* University of Twente, Enschede, Netherland, 203-214.

Peter, B., Shiv, G. K. & Richard, E.D. (2011). Transiently stable emulsions for metalworking fluids, *Illinois Sustainable Technology Center Prairie Research Institute,* University of Illinois at Urbana-Champaign, 8

Rowe, G. W. (1968). *An Introduction to the Principles of Metalworking. London:* Edward Arnold Ltd. 26

Sutcliffe, M. P. F., Combarien, R., Repoux, M. & Montmitonnet, P. (2002). Tribology of plane strain compression tests on aluminum strip using Tof-Sims analysis of transfer films, *Journal of Wear,* 254, 65-79,

Tekayya, A. E. & Altan, T. (2012). Sheet metal forming – fundamental. *American Society of Materials.* 89.

Watts, A. B. & Ford, H. (1952). An experimental investigation of the yielding of strip between smooth dies, *Processing Institute of Mechanical Engineering,* B1, 448-453.