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Influence of formulated neem seed oil and jatropha curcas seed oil on wire drawing of mild steel and medium carbon steel at elevated temperatures

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HIGHLIGHTS

- *Influence of formulated neem seed oil and jatropha curcas seed oil on wire drawing of mild steel and medium carbon steel.*
- *Antimony dialkyl dithiocarbamate in neem seed and jatropha seed oils can reduce drawing stresses at high temperatures by lowering the coefficient of friction of the drawing tribo-system.*
- *Formulated neem seed and jatropha seed oils are good lubricants for wire drawing of mild steel and medium carbon steel.*

ABSTRACT

So many facets of hot wire drawing process, despite its extensive and long time employment in the industries, still remain unclear, due to want of systematic investigation of the process. This work investigated the influence of formulated neem seed and jatropha seed oil as lubricants, using antimony dialkyl dithiocarbamates (ADTC) as an additive, on wire drawing process. The suitability of the bio-based oils in friction and wear control during wire drawing process were investigated, using a four ball tester. Experimental drawing process, using a Tungsten Carbide die and the formulated lubricants was carried out on mild steel and medium carbon steel rod (6 and 8mm diameter respectively) at temperatures from 20^{O}C to 750^{O}C, on a drawing bench. The stresses and the temperature distribution profiles along the work-piece were reported. Up to 45% of reductions in area, without wire fracture, achieved on the drawing of the medium carbon steel have equally been reported.

Keywords:
| Hot-drawing | Mild/Medium carbon steels | Neem oil | Jatropha oil |

1.0 INTRODUCTION

So many facets of hot wire drawing process, despite its extensive and long time employment in the industries, still remain unclear, due to want of systematic investigation of the process (Hakansson, 2015). However, it is widely known and accepted that the geometries of the die, metallurgy of the wire material, the drawing speed, reduction in area of cross-section of the wire, and the lubricating oil employed are at the frontlines of the factors which influence the wire drawing process. A careful selection of the stated parameters is paramount to a successful high temperature drawing operation.

The wire drawing process is quite simple in concept, the wire is prepared by shrinking the beginning of it by hammering, filing, rolling or swaging, so that it will fit through the die; the wire is then pulled through the die as shown in Figure 1 below (Das et al., 2013). As the wire is pulled through the die, its volume remains the same, so as the diameter decrease, the length increases. Usually the wire will require more than one drawn, through successively smaller dies, to reach the desired size. During wire drawing the process deformation is accomplished by a combination of tensile and compressive stresses that are created by the pulling force (applied at the exit of the die) and by the die geometry.

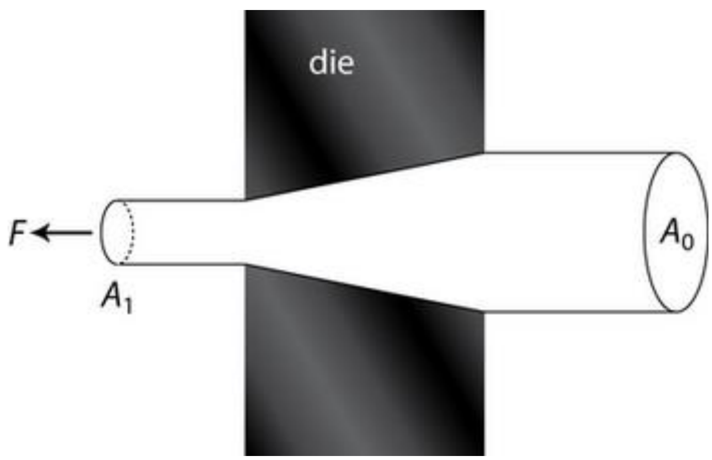

Figure 1: Schematic Wire drawing concept

According to Schade, 2006, in wire drawing, the equation for drawing stress was derived by Brulez from the slab method as

$$\sigma_D = \sigma_{bp} + \sigma_F In(D_o/D_i)^2 + \tau_c In(D_o/D_1)^2 (tan\alpha + cot\alpha) + \tau_d(4l/D_1)$$
$$+\sigma_f\left(4tan\alpha/3\sqrt{3}\right) \quad (1)$$

Where; $\sigma_D = Drawing\ stress$
$\sigma_F = Fatigue\ limit$
$D_o = wire\ diameter\ before\ drawing$
$D_1 = wire\ diameter\ after\ drawing$

With the terms on the right-hand side consecutively represent the following:

a) back pull stress,
b) the uniform change in shape with flow stress under process conditions which depend on velocity and temperature,
c) friction shear stress at the interface of wire/cone part of the die,
d) friction shear stress at the interface of wire/cylindrical part of the die, and
e) a representation of the redundant deformation due to the internal shear effect in the wire.

As submitted by (Vega et al., 2009; Fu et al., 2013). They studied the effect of the process variables such as semi die angle and reduction in area, and the coefficient of friction on the drawing force value, their results clearly indicated that friction has significant effects on the drawing force which decreases with the decrease of area reduction. The optimum die angle for wire drawing is assumed to be obtained when the plastic strain distribution across the diameter of the wire becomes uniform.

From the fundamentals of wire drawing theory, friction exists at the interface of the material being drawn and the die. This friction forces, while could exposed the die/material surfaces to wear, it equally induces shear stress unto the material surface. The rate of die wear must be kept at the barest minimum to ensure long die life, good wire metal flow, tolerance of the drawn wire and the economy of the drawing process (Jianxin et al., 2006*)*. The magnitude of the induced shear stress, mathematically, is equals the product of the pressure normal to the interfacing line between the die and the material and the dynamic friction coefficient of the rubbing surfaces. This friction phenomenon is unwanted; hence it is minimized by the use of lubricants.

The efficient performance of the die and the quality of the wire drawn are largely influenced by the lubricating oil used (De Garmo et al., 2011). During the process of deforming the wire, the lubricating oil performs the role of keeping the die temperature low, reducing frictional forces between the die-wire contacting surfaces, and minimizing wear of the die by forming a thin tro-film between the said surfaces (Wright, 2011). It is generally accepted that the phenomenon of friction is one of the most important parameters responsible for die wear, and quality of the wire drawn (Vega et al., 2009; Haddi et al., 2011; Aminzahed et al., 2015). Hence good wire quality and die protection against wear is achieved by the use of proper lubricant that provide stable film between the die-wire interfaces. The type of lubrication regime that exist between the wire-die interfaces is elastohydrodynamic type where deformation of at least one of the contacting surfaces occurs during the relative motion. This normally squeezes the oil layer out of the contact-surfaces, owing to high load. The situation is worse off in hot metal working, where the metals are plastically deformed above recrystallization temperature. This elevated temperature is necessary to lower considerably, the hardness and yield strength, while increasing the ductility of the wire material to a significantly high level (Khan et al., 2016). The oil that must ensure lower friction in this situation must be equipped with potent friction modifier(s) and anti-wear agent(s).

The global need to conserve energy, reduce cost, and to employ environmentally friendly lubricating fluid in metal forming processes, remains a challenge to researchers in the industries and the academics. The challenges cover the development of more effective coating techniques, lubricating methods and more efficient lubricating fluids. The petroleum-derived wire drawing lubricating oil, though effective, and could be developed to be more effective, are high pollutants.

The competition noticed between the food sectors and industrial lubricants sectors, as vegetable oils are being engaged for industrial lubricants usage, have prompted the search for non-edible oils as suitable means of resolving the problem (Binfa et al., 2015*)* Vegetable oils are considered promising in achieved the goal of energy conservation, cost reduction and environmental safety in drawing operation. This is because for some decades now, vegetable oils had been identified to be non-toxic and readily biodegradable base stocks for industrial lubricating oil formulation (Quinchia, et al., 2014), owing to their attractive intrinsic lubricant properties, such as high lubricity, high flash points, high viscosity indices, and good solubility of additives molecules (Baumgart, et al., 2010; Salih et al., 2013), among others. Of particular interest in the current work is their special ability to form tribological matrix, with strong attachment to metal surfaces (Pujari et al., 2013*)*, such that they are not easily desorbed by mechanical and thermal stresses. However, the challenges with vegetable oil in meeting lubricant performance are thermo-oxidation stability, and insufficient tribological performance at very high temperatures, such as in the case of hot drawing process.

The work reported in this paper is an investigation of the influence of formulated neem seed and jatropha seed oil, using antimony dialkyl dithiocarbohate (ADTC) as an additive in the oil formulation, as lubricants for wire drawing. The experimental drawing process was carried out using tungsten carbide die, and mild steel and medium carbon steel rod of 6 mm and 8 mm diameter respectively as raw materials. The drawing was done at temperatures varying from 100°C to 750°C.

An equilibrium solution was used to describe and predict the process of deformation at the stress and temperature distribution profile along the work-piece.

2.0 MATERIALS AND METHODS

2.1 Materials

The materials used in this work were hot rolled product with 6 mm in diameter mild steel and 8 mm in diameter medium carbon steel, this were chosen because of their excellent workability, a relatively low work hardening rate and are readily available since they are relatively inexpensive. The choice was in line with the previous research on the mechanics of drawing bars from the round. The chemical compositions of the wire materials were determined as shown in Table 1.

Table 1: Chemical compositions of mild steel and medium carbon steel (wt %)

Material/ Composition	C	Si	Mn	S	P	Cr	Ni	Al	Cu	Mg	Ti	Zn	Fe
Mild steel	0.05	0.01	0.04	0.014	0.016	-	-	0.033	-	-	-	-	-
Medium carbon steel	-	0.35	0.021	-	-	0.05	-	97.9	0.1	0.35	0.1	0.15	0.1

2.1 Oil Formulation

Fundamentally, almost all lubricants require further additives to impart other characteristics of a non-tribological nature, such as oxidation resistance, corrosion protection, and detergency. Most cutting fluids, vegetable oils and petroleum-based, are compounded or modified to achieve these requirements. Several methods are available to modify these oil lubricants. (Schwab and Gast, 1970). The important and most commonly used methods are sulfurization and phosphate modification. In this study, the chemico-physical characteristics of the tested oils is shown in Table 2.

This test was carried out based on ASTM D4172: Standard test method for wear preventive characteristics of lubricating fluid (four-ball method). A steel ball of 12.7 mm in diameter was washed using methanol, wiped dried with industrial tissue, it was then mounted on the motor spindle of a four ball tester, and pressed into the cavity of three balls, clamped in a ball cup filled with lubricant to at least 3mm above the three balls. The ball in the spindle, refer to as the rotating ball normally makes a point contact with each of the three balls. The settings were loaded with 392 N static load, and the lubricating oil is heated to 75°C using an inbuilt heating device. The motor spindle was set rotating at 1200 ± 60 rpm for 60 minutes, 10 seconds. The loading, temperature, speed and time were set on the controller, interfacing the four ball machine and Winducom 2010 software installed on a PC, was used for extracting the experimental data. After the 60 minutes 10 seconds, the three lower balls were removed, cleaned with methanol and industrial tissue and the scar diameters made on them owing to friction between their contacting surfaces with the top rotating ball were measured using an optical microscope.

All relevant data from the software and microscope were recorded and analyzed respectively.

Table 2: Chemico-physical characteristics of neem seed and jatropha curcas seed oils

Properties	Neem oil	Jatropha oil
Viscosity @ 40°C (cPoise)	175	235
Viscosity @ 100°C (cPoise)	73	131
Viscosity Index	345	480
Refractive Index	1.47	1.50
Sulphated Ash	0.015	0.40
Acid Value/Total Base	1.5	3.5
Pour Point (°C)	1.3	0.2
Density (kg/m^3)	1.40	150.5
Colour	Light Brown	Black
Flash Point (°C)	260	275

2.2. Drawing

The drawing exercise was performed base on the procedure reported by Hillery and McCabe, 1995. The wire to be drawn was cut to lengths and the tips pointed to 3.9 mm, and fed through lubricating oil and the orifice of the die, after thorough cleaning and degreasing. The infrared pyrometer (for temperature measurement), and the drawing speed were adjusted. Drawing of a short length of wire was met after taking up the initial slack. Settings for the require temperature for the drawing process was achieved by adjusting the induction heater to the proper power position using the rheostat. The drawing process was commenced, and the induction heater switched on short thereafter. Recordings of the loading, the wire temperature at the die entrance, and the induction heater power indicator were done on the AVO meter during the drawing process. The remaining information were recorded, and labelling of the drawn wire (for ease of identification in the future) was down to complete the exercise. The design of experiment as shown in Table 3.

Table 3: Drawing experimental design

Material	Lubricant	Pressure die nozzle semi-angle (degree)	Area reduction (%)	Drawing speed (m/min)
Mild steel and medium carbon steel	Neem oil and jatropha oil	6, 8, 10	25, 32, 35, 38, 55	20, 25, 35, 45, 55

3.0 RESULTS AND DISCUSSION

3.1 The Four-Ball Wear Test

Formulation of the two oils for reduction of friction and wear was done by testing each of the oils, treated with several concentrations of ADTC, using a four-ball tester, based on ASTM D4172 method. From Figure 2, it is noticed that 0.5 wt% ATDC in JO produced friction coefficient of 0.046, even lower than the typical range (0.05–0.08) in wire drawings, reported in the literature. However, this additive proportion in the oil made insignificant change in wear scar diameter (0.682 mm), as shown in Figure 3. NO (Neem oil) step up friction and wear especially with lower concentrations of ADTC, until at concentrations of 0.75 and 1 wt%, where it had the level of friction reduction as JO (Jatropha oil). The ability of ADTC to lower the friction coefficient of the four-ball rubbing arrangement in JO shows that fatty acid molecules of JO are compatible with antimony compound. In such compatible atmosphere, the active antimony radicals from the compound interact with the initial worn surface of the steel balls by chemically impregnating and altering the metallurgical structure of the surfaces to form hard and low shear strength layers in collaboration with the attaching polar heads of the oil molecules. This formation results in alliance of layer arrays that promote friction reduction, and oppose high wear of the surfaces, as documented by (Bongfa et al., 2016; Bongfa et al., 2015).

However, the poor performance in NO is probably an incompatibility issue, or presence of contaminants in the base oil, or unsuitable test condition(s) for the tribological activities of antimony in NO, because antimony is noted to have varied mechanisms of operation in different base oils.

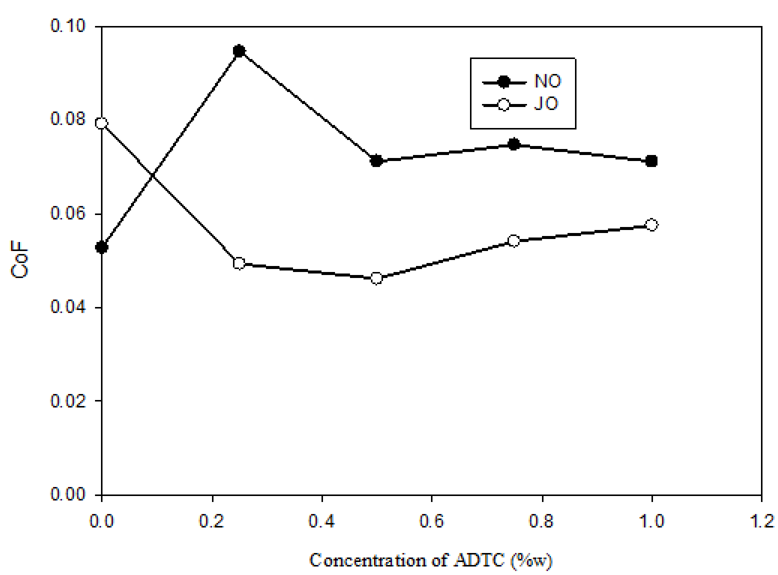

Figure 2: Plot of coefficient of friction (CoF) versus concentration of ADTC in the oils

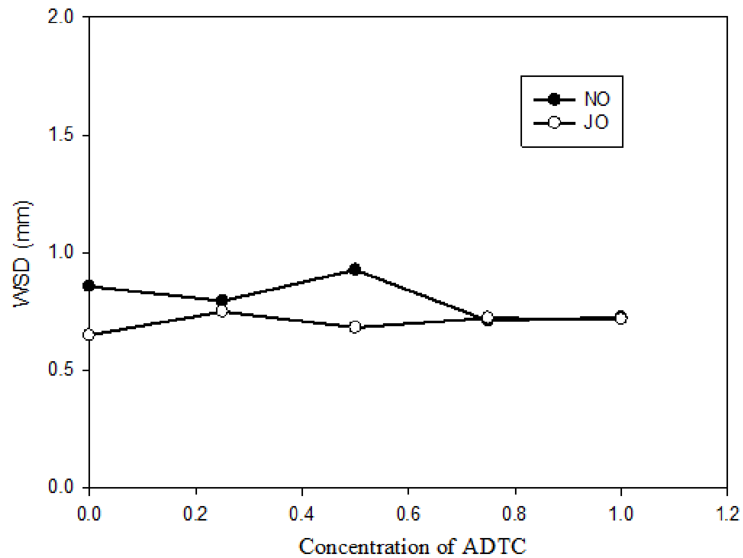

Figure 3: Wear scar diameter (WSD) versus the concentration of ADTC in the oils

3.2 Wire Drawing Test

Figures 4 and 5 report the variation of drawing stress, the yield tress and maximum stress against drawing temperature, during the drawing operation of mild steel, and medium carbon steel respectively. It can be seen from the plots that the performances of NO are within the same levels with those of JO in this tests, despite higher friction coefficient by the former under friction and wear test condition. This should be that ADTC requires higher temperatures (since wear test was done at 75°C) to dissolve and collaborate with the polar molecules of NO for effective friction and wear control.

Successful drawing of wires involves numerous interactions among certain parameters, including the drawing tool properties, the drawing conditions (state of stresses, reduction in area, drawing temperature, drawing speed, the die parameters), the wire material properties, the lubricant and the nature of lubrication (Schade, 2006). Here, the influence of new bio-based lubricants on the stresses at various high temperatures was revealed.

The involvements of the two oils as lubricants in the system resulted in the listed stresses – temperature relationships, comparable to those reported elsewhere. The curves reveal that the additives, through the carrier backbones of the base oils, effectively reduce the drawing stresses by lowering the coefficient of friction of the drawing tribo-system, as the temperature rises. When the CoF is reduced, the shear stresses due to friction at the wire/die interface at both the cylindrical (τ_d term in Equation (1)) and conical (τ_c term in Equation (1)) portions of the die will reduced, and consequently lower the drawing stress. The implication is that wire failures such as ductile fracture (owing to high friction forces), crow's feet, occurring from maximum drawing stress enhancement, and cup and cone fracture (owing to poor lubrication), during drawing process will drastically reduce.

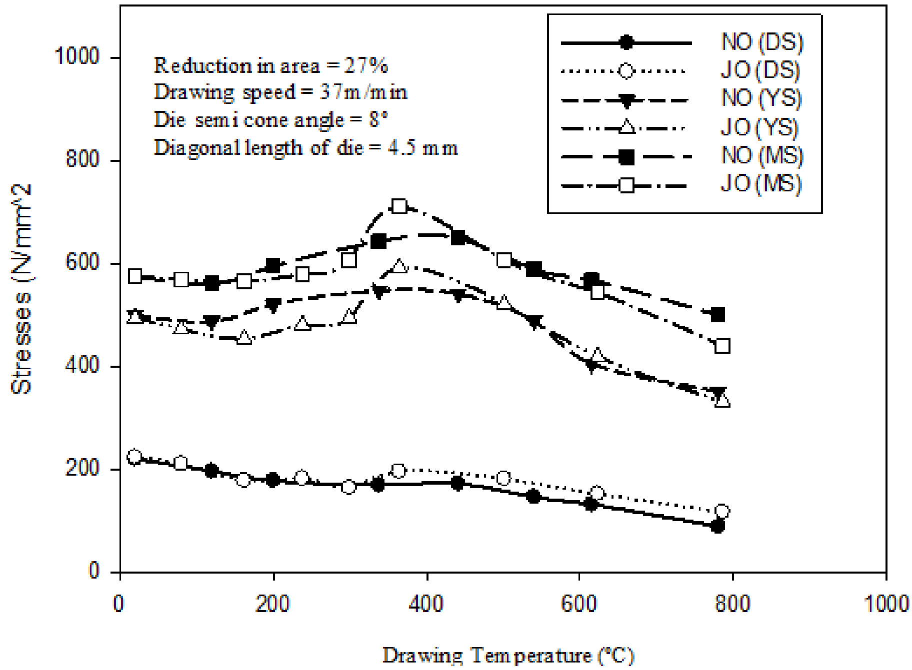

Figure 4: Drawing stress (DS), yield stress (YS), and maximum stress (MS) verses temperature for mild steel, lubricated with the formulated oils

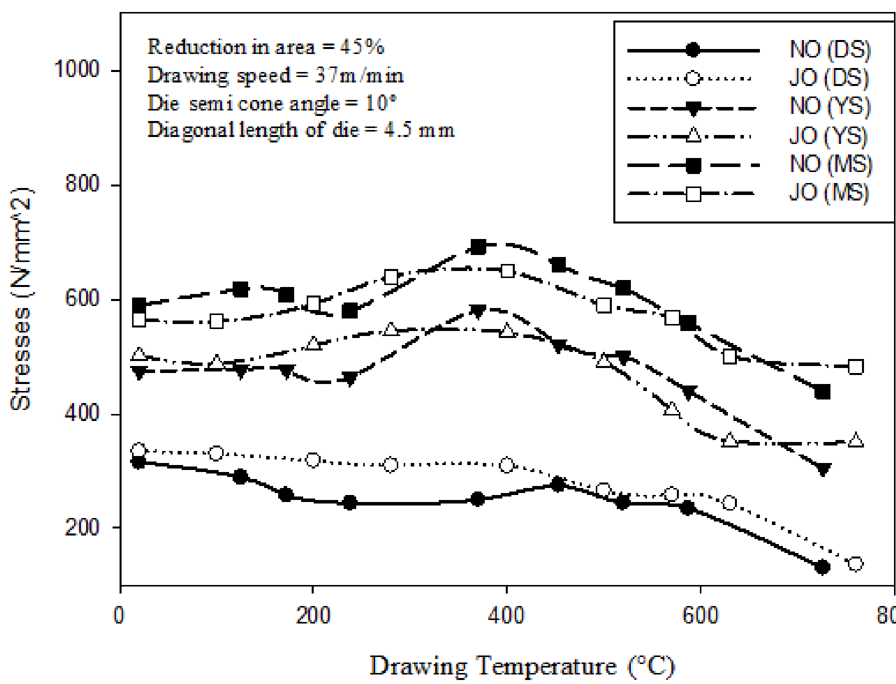

Figure 5: Drawing stress (DS), yield stress (YS), and maximum stress (MS) verses temperature for medium carbon steel, lubricated with the formulated oils

The reduction of the friction forces by the two oils in the case of the mild steel were following the same trend at low temperatures, until at somewhere around 300°C, after which the formulated NO increased its effectiveness above the JO for all the remaining higher temperatures in the test. In the drawing of the medium carbon steel, the NO-based lubricant express superiority over the JO-based oil, in friction reduction, for all the regime of the temperature in the test. The NO-based oil should have higher stability, and surface absorption energy than the JO-based oil. The polar heads of the NO, the antimony and the sulphur from the additive compound (upon decomposition) could form a matrix arrays of stronger absorbent to the wire and die contacting surfaces, and stronger lateral intermolecular forces that defy desorption by high temperature and high load. These phenomena will maintain a stable friction reducing film at the interfaces of the contacting elements. The non-equitability of the performance of the two oils even though formulated with same proportion of the same additive connote that, additives function differently in different base oils. The contradiction of the friction reduction characteristics of NO-based oil in drawing application from the formulation tests shows that formulated oils function by different mechanisms in different combination of tribo-pairs in which they are employed.

The yield stress and maximum stress at all the drawing temperatures of mild steel wire for JO were lower than those for NO, except for the overshoot at about 400°C (Figure 4). This is probably due to better cooling of the wire by JO, as it passes through the die.

In the case of the medium carbon steel (Figure 5) the yield stresses at temperatures lower than 350°C were higher during the drawing process with JO as the lubricant than with NO. However, at temperatures higher than 350°C, lower yield and maximum stresses were experienced by JO, until close to 750°C where both the maximum and yield stresses increased and became higher than the recorded values under NO as lubricant. This could mean that JO formulated oil exhibits better cooling and friction reduction effect than NO, at several ranges of the temperature until at the approach of peak temperature where it rapidly started breaking down, possibly due to oxidation degradation.

The two-formulated oil were effective in friction and wear control in mild steel and medium carbon steel wire drawing processes. They can be good eco-friendly, and renewable-source replacements for petroleum-derived wire drawing fluids.

CONCLUSION

Neem seed and jatropha seed oils had been formulated, using antimony dialkyldithiocarbamate, for hot wiring drawing of metals. The tribological behaviour of the formulated oils were tested, using a four-ball wear tester, and the application tests were performed on a wire drawing test bench. Jetropha formulated oil at 0.5% (wt) of the additive, showed the best reduction of friction coefficient (from 0.080 to 0.046), while Neem seed oil step-up friction forces when formulated with several proportion of the additive, as tested on the four-ball testing machine. Each of the formulated neem and jatropha seed lubricants (with 0.5% wt of the antimony compound) were used to perform wire drawing operation (using 6 and 8 mm diameter mild steel and medium carbon still rods respectively, as the raw materials) on the wire drawing rig. From the results, low drawing, yield, and maximum stresses were obtained in all the tests, at temperatures from 20 to 750°C, with each of the oil as lubricant. Contrary to the outcome of the four-ball tests, lower drawing stresses were achieved with neem seed formulated oil than that of jatropha, but lower yield and maximum stresses were dominant in the tests with jatropha formulate than neem-based oil. The drawing process at high temperatures achieved reductions of up to 45% in the wire cross-sectional area of medium carbon steel, by passing the drawn wire through the die without wire fracture. It is convincing from the outcome of this work that the formulated oils can be good non-toxic, biodegradable, renewable alternative lubricant for high temperature wiring operations.

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