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Development of Castor Oil – Graphite Lubricants for Cold Extrusion of Aluminium Alloy

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ABSTRACT

The study was conducted to develop castor oil – graphite lubricants for cold extrusion of aluminium alloy and to investigate the effect of the developed lubricant on the extrusion pressure of aluminium alloy. Cold extrusion process at a constant extrusion ratio of 1.25:1 was used on 14mm diameter by 30mm long aluminium alloy billets. Experimental results showed that onset pressure ranges from 19.857MPa to 13.652MPa and final pressure ranges from 17.168MPa to 12.411MPa for formulated lubricants. Onset pressure of 21.718MPa and final pressure of 18.616MPa for unlubricated extrusion and onset pressure of 15.720MPa and final pressure of 13.238MPa for standard lubricant were obtained. Compared with unlubricated extrusions, lubrication ensured a drop in onset and final pressures by 5.998MPa and 5.378MPa, respectively for standard lubricant and a drop in onset and final pressures by 8.066MPa and 6.205MPa, respectively for the optimum formulated lubricant with 15% graphite and 85 % castor oil. The tribological properties of the formulated optimum lubricant were found to be 7.31, 171.2oC, 0.93g/cm3, 1.0546cSt, 0.939 and 2.294J/kgK for pH value, flash point, density, viscosity, specific gravity and specific heat capacity, respectively. The optimum formulated lubricant significantly reduced extrusion load and is considered satisfactory for cold extrusion of aluminium alloy.

Keywords: Castor Oil, Final Extrusion Pressure, Graphite, Lubricant, Onset Extrusion Pressure, Triobological Properties.

I. INTRODUCTION

Extrusion is a metal forming process, wherein a billet or slug of material is forced by compression to flow through a suitably shaped aperture in a die to give a product of smaller, but of uniform cross-section (Onawola and Adeyemi, 2002). The extrusion process can either be hot or cold. Cold extrusion is the plastic deformation of metals below the recrystallization temperature. The deformation is usually performed at an elevated temperature in order to provide increased ductility and reduced strength (Black and Kohser, 2008). In cold extrusion, materials are made to flow by the application of high pressures. Thus friction forces are developed by the reaction of the billet with the container wall and die with consequential increase in deformation load leading to energy wastage and damage to the die (Ibhadode, 2001 and Bowden and Tabor, 1974).

The application of appropriate lubricants to die and work piece will minimize these effects, thereby producing a product with good surface finish. Lubrication plays an important role in cold extrusion since efficient lubrication prevents direct metallic contact, with the reduction of extrusion loads and wear, and the improvement of products quality and tools life (Caminaga et al, 2006). Lubricants are vital in aluminium extrusion as they do not only improve the surface finish of the product but could also act as a heat insulant between the billet and the die (Obi and Oyinlola, 1995), both effects tending to lengthen die life. Thus, a good lubrication is necessary to reduce detrimental effect of the high temperature and pressure on the die life as well as on other components.

Lubrication is very important in metal forming operations. Effective lubrication results in controlled friction, with consequential reductions in force and power requirements and in tooling stresses and defects (Wick et al., 1984). Different lubricants have been developed and used for various metal working processes. These include among others; tallow oil, talc, grease, palm oil, graphite in water or oil and molybdenum disulphide (Lange, 1985).

In modern manufacturing set ups, the production, application and disposal of lubricants have to cover the requirements for the best possible protection of our environment. Often health hazards do not follow the direct way to human beings, more often they follow indirect routes through our environment. Since the environment is being increasingly contaminated with all kinds of pollutants, any reduction in the sources of pollutants is highly welcome. It has been stated that 5-10 million tons of petroleum-based oleo chemicals enter the biosphere every year (Syahrullail et al, 2011 and Lazzarotto et al, 1998). About 40% comes from spills, industrial and municipal wastes, urban runoff, refinery processes, and condensation from marine engine exhaust (Gawrilow, 2003).

Today, vegetable oils are much desired for their application as lubricant in metal forming processes, because they are renewable resources and do not cause harm to the environment compared to mineral oils (Syahrullail et al, 2011 and Lazzarotto et al, 1998). Although the biodegradability level of vegetable oils are slow they are, nonetheless, better compared to petroleum based lubricants. In a related work, Abere and Adeyemi (2008) reported that vegetable oils offer excellent lubricating properties, they are non-toxic, biodegradable, relatively inexpensive compared to synthetic fluids, and are made from natural renewable resources.

One of the possible lubricants that can satisfy lubrication need is vegetable oil which can offer significant environmental advantages with respect to resource renewability, biodegradability, and adequate performance in a variety of applications (Komiya, 2005). Natural fatty acid oils such as castor oil, palm oil, rapeseed oil, soybean oil, sunflower oil, and tallow oil have been used as lubricants for years. They are the so-called triglycerides of more or less unsaturated fatty esters. This type of base is completely biodegradable (Bartz, 2006).

Castor oil is obtained from the seed of castor plant which has a botanical name Ricinus communis. Castor oil is not only a naturally-occurring resource, it is inexpensive and environmentally friendly. Castor oil is viscous, pale yellow, non-volatile and non-drying oil with a bland taste and is sometimes used as a purgative. It has a slight characteristic odour and the crude oil tastes slightly acrid with a nauseating after-taste. Relative to other vegetable oils, it has a good shelf life and it does not turn rancid unless subjected to excessive heat (Ogunniyi, 2006).

Graphite is known to be a chemically stable dry lubricant with good heat resistance. It is very abundant in nature. It is an inert compound. Graphite powder is lubricious (Lange, 1985). In this work, castor oil - graphite lubricant was formulated for use in extrusion of aluminum alloy. The effect of the formulated lubricant on the extrusion pressure was assessed to determine the efficacy of its use. Comparison of the performance of the optimum formulated lubricant with a standard lubricant and the relevant tribological properties of the optimum formulated lubricant were carried out.

II. METHODS AND MATERIAL

A. Materials

Round aluminium alloy 1350 (EC Grade) bar scrap with the properties given in Table 1 was obtained from former Power Holding Company of Nigeria (PHCN) Transmission Works Centre, Yola, Adamawa State.

Table 1: Some Properties of 1350 Aluminium Alloy

Composition, % by weight			Strength, MPa		Melting Temperature, °C
Al	Si	Fe	Yield	Tensile	
99.50	0.10	0.40	24.13	58.61	634

Graphite powder pulverized to the finest particle size in accordance with ASTM D1514-01 standard test method was obtained from Northern Scientific Laboratory, Jimeta- Yola, Adamawa State, North-Eastern Nigeria.

Cold pressed castor oil was used because of its low acid value and low iodine value. The oil was obtained from Affcot Oil Mill along Yola - Numan Road, Yola, Adamawa State.

A petroleum based lubricant was obtained from Towers Aluminum Extrusion Division, Dopemu, Lagos, Nigeria and was used as standard reference lubricant.

B. Methods

Formulation of the castor oil – graphite (COG) lubricant was done in accordance with recommended 90 - 45% oil (Duncan et al., 2000). In this study, 10, 15, 20, 25 and 30 (w/w %) graphite were mixed with 90, 85, 80, 75 and 70 (w/w %) castor oil, respectively at ambient temperature of 28.5^{o}C.

1) Melting and Casting of the Aluminium Scrap: The Aluminium alloy scraps were cut into smaller sizes and melted in Morgan Crucible Furnace and sand cast into billets which were then machined into rod of 14mm diameter and 30mm length using universal lathe machine. Thereafter, the billets were pre - heated in an electric furnace at 160^{o}C for duration of 1 hour in accordance with Onawola and Adeyemi (2002).

2) Determination of Extrusion Pressure: An extrusion rig consisting of a 25 ton hydraulic press, a container (chamber) to receive the work piece, a tool carrier for housing the die and support tooling and a ram that applies the extrusion pressure was used for the cold extrusion of the aluminium alloy. The extrusion was done through a die orifice of constant diameter of 12.5mm (i.e. constant extrusion ratio).

The direct extrusion method was adopted in which the billet moves relative to the container wall. The required lubricant was applied by hand using brush due to suitability of this application method for small batches (Eugene and Theodore, 1996). The lubricant was applied to the die face and the end of the ram to ease release at the end of the extrusion process. Billet measuring 30mm long x Ø14mm and preheated to a temperature of 160^{o}C was loaded into the container.

Pressure was applied through the ram, which exerts force on the billet causing it to move forward and forcing the billet through the die thus reducing the diameter of the work piece to 12.5mm. The container and die positions are fixed. The billet moves relative to the container. Billet movement created the friction between the billet and container wall, which increased the force required to extrude the aluminium alloy through the die. At the start of the extrusion process, the pressure on the billet increased rapidly to a maximum value at which time the billet began to flow through the die aperture. As the billet extrudes through the die, the pressure required to maintain deformation progressively decreased. The maximum pressure recorded at the start of the extrusion process was referred to as 'onset extrusion pressure' (OEP) or breakthrough extrusion pressure (BEP) while the one required to maintain flow of the billet through the die was termed final extrusion pressure (FEP). The extrusion was stopped when almost 80 percent of the billet has been extruded while the remaining portion was not extruded but discarded as scraps.

Aluminium alloy billets were also extruded using the standard extrusion lubricant obtained from Towers Aluminium Extrusion Division at Dopemu, Lagos and both the OEP and FEP were determined. Each of the lubricant samples was tested five (5) times on aluminium billets at a constant extrusion ratio of 1.25:1 and the average extrusion pressures were calculated and recorded. The extrusion was also carried out without lubricant.

3) Determination of Tribological Properties of the Optimum Formulated Lubricant: The optimum lubricant was investigated for its tribological properties such as viscosity, flash point, pour point, specific gravity, density, pH value, specific heat capacity in accordance with Nigerian Industrial Standard (1997).

Viscosity: The apparatus used for the experiment were rotational viscometer (Visco star plus L) model No:VSCL110458, 50ml beaker, stirrer, and a thermometer. The kinematic viscosity of the lubricant was determined by first preparing a sample lubricant which was then put in a beaker with a stirrer. The viscometer was then switched on and the measuring configuration was selected. The temperature was noted at 28.5^{o}C. The time was set to 30 seconds. The viscometer was started using "ON" button. The spindle started moving and viscosity of the sample lubricant was displayed after every revolution of the spindle and recorded.

The dynamic viscosity was calculated using equation 1 (Eugene and Theodore, 1996).

$$cSt = \frac{cP}{\rho} \qquad (1)$$

Where, cP - viscosity in centipoise
ρ - density in g/cm^3

Specific Heat Capacity: Apparatus used included well-lagged calorimeter with a stirrer, thermometer, heating furnace and electronic weighing balance.

The method of mixtures was employed for the determination of specific heat capacity of the lubricant. A rectangular brass of mass 90g was used. The mass and the initial temperature of brass were recorded. The solid brass was heated in a furnace at 140 ^{o}C for 45 minutes. The calorimeter was set up with the lubricant under test. The heated solid was transferred quickly to the calorimeter while stirring gently. The rise in temperature of lubricant was recorded until the temperature remained constant and thus the final temperature of the lubricant and the brass became uniform.

Assuming no heat is lost to/gained by the surroundings, heat gained by calorimeter and lubricant is equal to heat lost by brass and hence the specific heat capacity was obtained using equation 2.

$$m_l c_l \theta_l + m_c c_c \theta_c = m_s c_s \theta_s \qquad (2)$$

Where, m_s, c_s, θ_s
Mass, heat capacity and temperature change of the solid brass, respectively;

c_s= 380J/kgK
m_c, c_c, θ_c – Mass, heat capacity and temperature change of the calorimeter, respectively;

c_c = 400J/kgK
m_l, c_l, θ_l – Mass, heat capacity and temperature change of the lubricant, respectively

PH Value: The apparatus consists of the potable pH meter (Extech), 50ml beaker, acidic buffer of pH 4, alkaline buffer of pH 9, distilled water and organic solvent. The pH meter was standardized using acidic buffer of pH 4 and alkaline buffer of pH 9. This was done to ascertain the working condition of the instrument. After that, the tip of the meter was washed in distilled water. The lubricant sample was poured into the 50ml beaker at room temperature of 29^{o}C. The clean electrode of the pH meter was placed in the oil sample. At a particular point in time the displayed reading reached equilibrium and was recorded as the pH value.

Flash point: The flash point was determined using manual pensky martens closed cup flash point tester (model 13661-3). The cup was filled with the lubricant sample up to the engraved line on the cup. The filled cup was placed into the batch (heater). The lid was fitted properly. The shutter activation shaft was placed onto the lid while engaging the tap with the shutter. A thermometer was inserted into the thermometer port on the lid. The flexi drive was held firmly with the large end fixed into the stir drive chuck and the small end fixed into the square socket on the stirrer. All the drive components were slightly rotated to be aligned properly. Stirrer speed was selected using the stirrer speed switch. The instrument was put on from the main switch. The stirrer was put on.

The pilot light was put on as well as the test flames. The test flame was ignited by the pilot light (flame). The pilot test adjuster screw was closed until the flames were blue balls approximately 4mm in diameter. The rate of temperature rise was set by adjusting the heater control knob. When the temperature began to rise, at every 2 degree rise, the stirrer was stopped and the test flame was dipped into the cup by rotating the stirrer activator knob clockwise to the stop so that the aperture was fully opened. At every dipping, it was observed whether flash has occurred. Heating was continued and manual dipping procedure was continued until flash point was obtained after which the instrument was turned off and cooling air supply was turned on.

III. RESULTS AND DISCUSSION

A. Results

The average OEP and FEP of the different samples of the formulated castor oil-graphite lubricant are given in Fig. 1 while the results of the tribological properties tests carried out on castor oil – 15% graphite (CO – 15% G) optimum lubricant that produced the lowest OEP and FEP during the extrusion are given in Table 2. The OEP and FEP of the extrusion optimum lubricant, standard lubricant and the extrusion process conducted without lubrication are presented in Fig. 2.

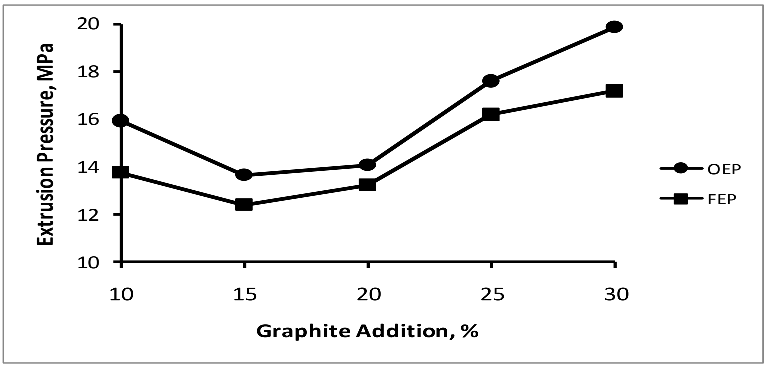

Figure 1: Variation in Extrusion Pressure versus Graphite Addition in the Lubricant

Table 2: Triobological Characteristics of CO – 15%G Lubricant

Density at 29^{o}C, kg/m^3	Dynamic Viscosity, cP		Kinematic Viscosity, cSt		Specific Heat Capacity, J/kgK	Specific Gravity	pH at 29^{o}C	Flash Point, ^{o}C
	Min	Max	Min	Max				
930	0.9805	1.0214	1.0546	1.0983	2.297	0.939	7.31	171.2

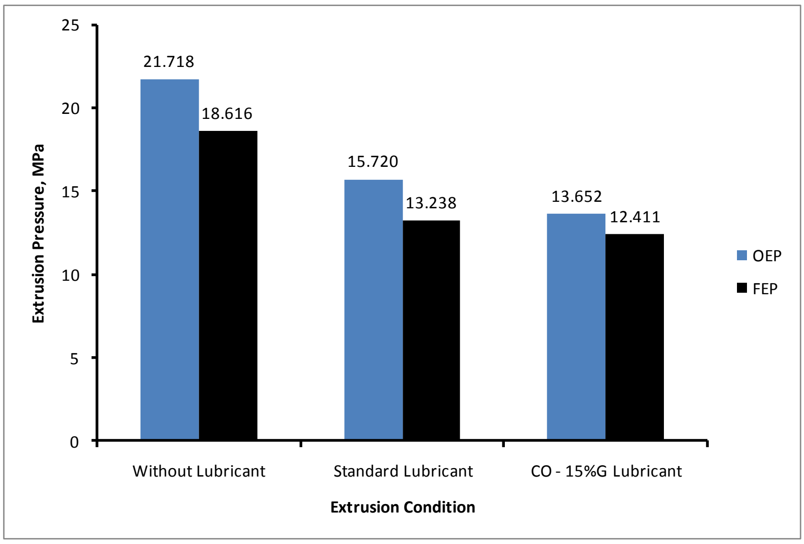

Figure 2: Comparison of OEP and FEP of the Three Lubrication Regime

B. Discussion

1) Extrusion pressure: During the extrusion process, the pressure was not uniform throughout the ram travel stroke. When the hydraulic ram started moving, the pressure on the billet increased rapidly to a maximum value (BEP or OEP) at which time the billet started to flow through the die aperture. The rapid rise in pressure during initial ram travel was due to the initial compression of the billet to fill the extrusion container before the commencement of the deformation. The pressure began to drop as soon as the billet started to flow through the die orifice. As the billet was being extruded through the die, the pressure required to maintain flow progressively decreased up to FEP with decreasing length of the billet in the container. This is because the friction between the billet and the container wall is reduced as the length of the billet within the chamber decreases.

Towards the end of the stroke, the pressure for extrusion began to increase rapidly again. This is due to accumulation of the unextruded part of the billet which adheres to the rear wall of the container in front of the ram. In most extrusion process, the rear portion of each charge is usually left unextruded and discarded as a butt (Wick et al., 1984). Experimental results showed that there was a pressure drop for lubricated die at an elevated temperature of extrusion. For the unlubricated extrusion maximum pressure of 21.718MPa was achieved. The lubricated extrusion with the formulated lubricant produced a maximum pressure of 13.652MPa while standard lubricant produced a maximum pressure of 15.720MPa.

The extrusion pressure decreased with increase in the amount of graphite powder in castor oil up to 15% by weight of graphite and then increased with increase in the quantity of graphite up to 30%. This shows that the optimum OEP of 13.652MPa was achieved while using 15% by weight of graphite powder in castor oil. The petroleum based lubricant (referred to as standard lubricant) was equally tested on the aluminium billets. The extrusion pressure value obtained for petroleum based lubricant was higher than the one obtained while using the formulated optimum lubricant CO – 15%G. This is an indication that the formulated lubricant has better performance when compared with the petroleum based lubricant.

2) Tribological Properties: The pH value of the formulated lubricant shows that it is slightly alkaline. This reduction in acidity was not unconnected with the presence of graphite powder which is inert. Organic acidity conveniently represent the degree of oxidation (Brandes and Brook, 1992), and therefore this lubricant is expected to have a longer life and hence acceptability as a lubricant since alkalinity is sometimes introduced for special properties and neutralization of fuel combustion products that are acidic (Cameron and Mcfethes, 1987).

The average flash point of the lubricant was 171.2^{o} C. The standard range of flash point for lubricating oils is between 40^{o}C and 360^{o}C (Bestsynthetic, n.d). The value obtained clearly indicates that the formulated lubricant can serve adequately the intended purpose.

The thermal capacity of lubricating oils varies from 2000J/kgK for mineral oils to 4200J/kgK for water (Brandes and Brook, 1992). The specific heat capacity of the lubricant sample was obtained as 2.294kJ/kgK which is close to that of mineral oils. This result can be said to be in agreement with similar vegetable oil investigated such as palm oil and refined cotton seed oil (Abere and Adeyemi, 2008).

The average density obtained was 930kg/m^3 at 29^{o}C. When compared with the standard range of values of between 700.0 and 980.0 kg/m^3 for lubricating oils (Halling, 1987 and Herguth, 2000), the density of the lubricant sample indicates its acceptability as lubricant.

The average specific gravity of the lubricant sample was obtained as 0.939. The standard range of specific gravity for lubricating oils is 0.7000 to 0.9800 (Halling, 1987). Dorfman (2000) presented specific gravities (at 15.5^{o} C) of red palm, cotton seed and groundnut oils as 0.9210-0.9240, 0.922-0.925, and 0.917-0.9209, respectively. The specific gravity is within acceptable range.

The standard kinematic viscosity for lubricating oils is between 2 and 300 centistokes (Halling, 1987). From the result for viscosities of the lubricant sample, the lubricant sample can be used as lubricant even though its dynamic viscosities (0.9805 – 1.0214cP) are slightly below the minimum range. The kinematic viscosities of the lubricant range from 1.0546 to 1.0983cSt. The low viscosity may not be unconnected with the presence of graphite additive.

IV. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations were drawn from the study:

1. The onset extrusion pressure values were 15.927, 13.652, 14.065, 17.582 and 19.857MPa for castor oil graphite (COG) with 10, 15, 20, 25 and 30% graphite, respectively while the final pressure values were 13.756, 12.411, 13.238, 16.175 and 17.168MPa for COG with 10, 15, 20, 25 and 30% graphite, respectively.
2. The formulated castor oil graphite lubricant that produced the lowest extrusion pressure has 85:15% castor oil graphite ratio.
3. The tribological properties of the optimum lubricant were 7.31, 171.2^{o}C, 0.93g/cm^3, 1.0546cSt, 0.939 and 2.294J/kgK for pH, flash point, density, viscosity, specific gravity and specific heat capacity, respectively.
4. Castor oil – graphite lubricant with 15% graphite is recommended for use as lubricant for cold extrusion of aluminium alloy (EC grade).
5. Performance test of castor oil graphite lubricant for cold extrusion of other aluminium alloys should be studied.

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