ASSESSMENT OF THE EFFECT OF CASTOR OIL-GRAPHITE LUBRICANTS ON THE EXTRUSION PRESSURE OF ALUMINIUM ALLOY

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(M.ENG/ME/04/0623)

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BY

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A THESIS SUBMITTED TO THE SCHOOL OF POST GRADUATE STUDIES, MODIBBO ADAMA UNIVERSITY OF TECHNOLOGY, YOLA IN PARTIAL FULFILLMENT

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JANUARY, 2013

DECLARATION

I hereby declare that this work entitled "Assessment of the effect of castor oil-graphite lubricant on the extrusion pressure of aluminium alloy" was written by me and it is a record of my own research work. It has not been presented in previous applications for a higher degree. All references cited have been duly acknowledged.

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Usman Baba Shehu Date

DEDICATION

This project is dedicated to my beloved parents, Alhaji Baba Shehu Makinta and Hajja Falmata .

APPROVAL PAGE

This thesis entitled "Assessment of the effect of castor oil-graphite lubricants on the extrusion pressure of aluminium alloy" meets the regulations governing the award of degree of Master of Engineering of the Modibbo Adama University of Technology, Yola and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

The effect of castor oil – graphite lubricants on the extrusion pressure of Aluminium alloy was studied using cold extrusion process at a constant extrusion ratio of 1.12. Aluminium alloy specimens with 14mm diameter and 30mm length were used for extrusion. Experimental results showed Onset pressure of 21.718Mpa and Final pressure of 18.616Mpa for unlubricated extrusion; Onset pressure of 15.720Mpa and Final pressure of 13.238Mpa for standard lubricant, and Onset pressures (range from 19.857Mpa to 13.652Mpa) and Final pressures (ranges from 17.168Mpa to 12.411Mpa) for formulated lubricants. These values compared favourably well because there were pressure drop for lubricated extrusions as compared with unlubricated extrusions. The extrusion pressure of standard lubricant dropped by 5.998Mpa (Onset pressure) and 6.205Mpa (Final pressure) while the optimum formulated lubricant sample B (15% graphite and 85% Castor oil) dropped by 8.066Mpa (Onset pressure) and 6.205Mpa (Final pressure). The formulated lubricant sample B was also found to possess the following Tribological properties: pH value: 7.31, flash point: 171.2^{o}C, density: 0.93g/cm^3, viscosity: 1.0546cSt, specific gravity: 0.939 and specific heat capacity: 2.294j/kgk. The experimental results showed that the use of lubricant significantly reduced extrusion load of aluminium alloy. The optimum formulated lubricant sample B is considered satisfactory for the extrusion of aluminium alloy.

KEYWORDS: Extrusion pressure, Lubrication and Performance evaluation.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

In metal working processes, be they bulk deformation processes or not, metal is displaced from one location to another within a work piece while its volume and mass remain essentially constant. These processes include rolling, forging, extrusion, drawing and sheet metal forming.

Extrusion is a metal forming process, whereby 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. In cold extrusion, materials are made to flow by the application of high pressures. Thus friction forces were 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 (Bowden and Tabor, 1974 and Ibhadode, 1997).

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 lubrications prevent 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 play an important role in aluminium extrusion which not only improves 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. So due to the high temperature and pressure, and its detrimental effect on the die life as well as other components, a good lubrication is necessary.

Several research works involving the effects of die geometry, extrusion speeds, loading rates and ratios of lengths to diameters of billets on the extrusion pressure P, of cold extrusion process have been undertaken (Onawola and Adeyemi, 2002) while research findings have been fairly restricted to development processes and assisting lubricants for warm or hot extrusion processes. The dependence of extrusion pressure on extrusion temperature in the direct extrusion of Aluminium was studied by Lang (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).

Petroleum as we all know is a finite source and our society is highly depending on petroleum for its activities. It has caused environmental problems such as rising carbon dioxide levels in the atmosphere which gives rise to an increase in the average temperature of the earth. If this trend is not checked, this global warming process will have widespread influences on the environment which eventually will threaten our way of life. Therefore mineral oils need to be replaced by alternative and sustainable sources.

Today, vegetable oil is much desired for its application as a lubricant in metal forming processes, because it is a renewable resource and does not cause harm to the environment compared to mineral oil (Syahrullail et al, 2011 and Lazzarotto et al, 1998). Although the biodegradability level of vegetable oils are slow but are better compared to petroleum based lubricants. In a related work by 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.

Today, 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 kind of pollutants, any reduction 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 waste, urban runoff, refinery processes, and condensation from marine engine exhaust (Gawrilow, 2003).

Many terms are used to describe environmentally acceptable lubricants such as positive, friendly, appropriate etc. But in general terms, biodegradability means the tendency of a lubricant to be ingested and metabolized by microorganisms (Bartz, 2006). In the same presentation, it was stated that complete biodegradability indicates the lubricant has essentially returned to nature. Partial biodegradability usually indicates that one or more components of the lubricant are not degradable. Castor oil is one the oil that has a complete biodegradability level (Bartz, 2006).

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 in 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 a plant which has a botanical name Ricinus communis (Ogunniyi, 2005). Castor oil is not only a naturally-occurring resources, 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 vegetables oil, it has a good shelf life and it does not turn rancid unless subjected to excessive heat (Ogunniyi, 2005). India is the world's largest exporter of castor oil; Other major producers are China and Brazil as shown in Table 1.1

Table1.1 Production volume of castor oil by major producers.

Major Producers		1996	1997	1998	1999	2000
		`000t	`000t	`000t	`000t	`000t
India		344	278	304	294	324
China Pr		73	83	80	91	105
Brazil		21	43	21	19	52
Thailand		10	9	9	7	5
E.U		9	10	7	8	8
Others		22	19	20	23	23
total		479	442	441	442	517

(Source: http://www.ciara.com.ar/estadize.htm)

The castor plant grows in the wild in large quantities in most tropical and sub-tropical countries. It is available at low cost and the plant is known to tolerate varying weather conditions. Specifically, castor plant requires a temperature of between 20^{o}C and 26^{o}C with low humidity throughout the growing season in order to obtain maximum yields. The weather conditions for its growth limits its cultivation to tropical areas of the world. It is produce in large volume in places like Potiskum in Nangere local Government area of Yobe State

Graphite is known to be 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 use.

1.2 Statement of the Problem

I. A major aspect of manufacturing is the extrusion of metal parts. Large amount of energy expended during metal extrusion is very much dependent on the amount of friction between the extrusion dies and work piece.

II. The choice of material for use in today's engineering is dictated, to a very great extent, by the duo of energy and environmental considerations.

III. The manufacturing industry uses a lot of lubricating oils in its day to day activities. A large proportion of lubricants pollute the environment either during or after use (Gawrilow, 2003). In as much as our environment is being increasingly threatened with all kinds of pollutants, any reduction is welcome.

IV. The disposal of the waste derived from mineral oil lubricants cause environmental pollution, threat to ecosystem and health. It is of significance to produce lubricants that are more suitable for metal forming process and at the same time do not present environmental problems.

1.3 Aim and Objectives

The aim of this work is to evaluate, the effect of lubricants on the extrusion pressure of aluminium alloy using castor oil as a base and graphite as additive. The specific objectives of this work are, to:

1. Formulate castor oil graphite lubricants.
2. Study the effect of lubricants on the extrusion pressure of aluminum alloy 1350 (EC Grade).
3. Establish the percentage of graphite in castor oil for optimum performance of the lubricant.
4. Compare the performance of the formulated lubricant that produced the optimum value of extrusion pressure with a standard lubricant used for extrusion by companies in Nigeria.
5. Determine the relevant Tribological properties of the formulated lubricant that produced the optimum pressure value.

1.4 Justification of the Study

Due to the high deformation load and its detrimental effect on the die life as well as other components, lubrication is necessary. If too much or too little lubricant is used during extrusion, it can cause some undesirable effect on the surface of aluminum (Sheppard, 1989). So in each case, the extrusion chamber and the die have to be cleaned. Available literature indicated the use of graphite in water or oil.

Castor oil and graphite are obtained in large volume in the north eastern part of Nigeria and are non-harmful to the environment. Castor oil is not only a naturally occurring resource; it is inexpensive and environmentally friendly. Castor oil being a non edible oil, its increased cultivation especially in developing countries and its use, can free up some edible oils used in industries for human consumption thereby creating job opportunity with direct consequences of boosting the economy and saving our foreign reserves.

1.5 Scope and Limitation

The scope of the study is to evaluate the effect of lubricants on the extrusion pressure of Aluminium alloy using castor oil as base oil within 90-60% by weight based on available literatures in terms of enhancing properties of the material with lower forming pressures and energy requirements. This formulation was taken after Hartley et al., (2000).

2.0 LITERATURE REVIEW

2.1 Process of Extrusion

In metal extrusion process, a billet or a workpiece is deformed plastically in which a workpiece is reduced in cross section by the application of compressive forces to it causing it to flow through a hole in a shaped die (Ibhadode, 1997). The reduced section thus acquires the shape of the die orifice. In extrusion, a billet substantially confined, is forced to flow under applied pressure through a die opening to form an elongated shape or tube. The process may be carried out hot or cold. Ductile non-ferrous metals such as aluminum, Zinc and copper alloys are widely extruded (Ibhadode, 1997).

Extrusion process has two main advantages over other manufacturing processes (Extrusion-Wikipedia-The free encyclopedia).These are its ability to create very complex cross-sections and work materials that are brittle, because the material on encounters compressive and shear stress. Aluminium is one of the commonly extruded metals and examples of products made from aluminium extrusions include profiles for tracks, frames, rails, mullions, and heat sinks.

Hydraulic presses are usually used in the aluminium industry because it has a solid ram and is of the simplest construction. It may be horizontal or vertical depending upon the direction of ram travel (Ibhadode, 1997). The presses are designed in such a way that the billet is charged into the breech end of the container, between the ram and the container. The main ram stroke must equal at least the maximum billet length plus the length of the container (Ibhadode, 1997).

2.2 Methods of Extrusion

Basically there are four methods of metal extrusion known in practice. These include direct or forward extrusion, indirect or backward extrusion, hydrostatic and impact extrusions (Wick et al., 1984). The extrusion processes can be done with the material hot or cold.

Direct extrusion, also known as forward extrusion is the most common extrusion process in which the die head is held stationary and a moving ram forces the metal through it. The container and the die positions are fixed; the ingot billet moves relative to the container. Billet movement creates friction between the billet and container surfaces, which increase the force required to extrude metal through the die. This friction also retards metal flow toward the billet surface and, in effect, increases the rate of flow at the interior of the billet (Wick et al., 1984). Long lengths of complex shapes, including decorative shapes, can be produced.

Indirect extrusion, also known as backward extrusion is a process in which the billet remains stationary while the die assembly located on the end of the ram, moves against the billet creating pressure needed for metal to flow through the die. In this method, the hollow ram containing the die moves into the billet from one end, and the other end is closed .The force exerted on the billet causes the metal to flow through the die and form the extrusion, which emerges through the hollow ram.

Indirect extrusion is not practiced widely because the hollow ram creates tooling support problems, limits the length of ram, and reduces the maximum width of extrusion cross section obtainable from a given billet diameter (Wick et al., 1984).

Hydrostatic extrusion is method of extrusion in which the container is filled with a fluid that transmits the pressure to the billet, which is then extruded through the die. There is no friction along the walls of the container because the billet is subjected to uniform hydrostatic pressure. It does not upset to fill the bore of the container as it would in conventional extrusion. This means that the billet may have a large length to diameter ratio (even coils of wires can be extruded). Because of pressurized fluid, lubrication is very effective, and the extruded product has good surface finish and dimensional accuracy (Cubberly and Bakerjian, 1989).

Impact extrusion is a method that combines extrusion and forging in a single press operation. The forged section of the part produced can be a base, flange or hub. The extruded sections can be of any essentially symmetrical, hollow or solid shape and can extend upward, downward or sideways form the forged section it is a form of indirect extrusion and is particularly suitable for hollow shapes (Ibhadode, 1997). In a related literature according to Wick et al., (1984), impact extrusion process is usually performed on a high-speed mechanical press. The punch descends at a high speed and strikes the blank, extruding it upwards. The thickness of the extruded tubular section is a friction of the clearance between the punch and the die cavity and it is restricted to softer metals such as lead, tin, aluminum and copper.

2.3 Classification of Extrusion Based on Working Temperature

Metal forming in general tend to be classified as hot working or cold working based on the temperature being deformed. In metal working operations, workpiece temperature can be one of the most important process variables. It can alter the properties of a material (Black and kohser, 2008).

Hot extrusion is basically a hot working process. Hot working is defined as the plastic deformation of metals at a temperature above the recrystallization temperature. In hot working, the deformation is performed under conditions of temperature and strain where recrystallization occurs simultaneously with the deformation. In order to achieve this, the temperature of deformation is usually in excess of 0.6 times the melting point of the material. It is important to note that recrystallization temperature varies greatly with different materials. Tin is near hot-working conditions at room temperature, steels require temperatures near 2000 ^{0}F, and tungsten does not enter the hot-working regime until about 4000^{0}F (Black and Kohser, 2008). Thus the term hot working does not necessarily correlate with high or elevated temperature, although such is usually the case.

In hot extrusions, the billet, mould and tooling are heated to temperatures between 550^{0}F (288^{0}C) and 1050^{0}F (566^{0}C) of aluminium to facilitate extrusion at available press capacity (Black and Kohser, 2008). In this process, no lubricant is applied to the container wall or billet surface. Only limited amount of lubricant are applied to the ram nose and die face or to the billet end faces, to prevent aluminium from adhering to the tool surfaces. Hot working takes advantage of decrease in flow stress at higher temperature to lower tool forces and consequently equipment size and power requirements. The principal variables which influence the force required to cause extrusion include the type of extrusion, the working ratio, the speed of deformation, and the friction condition at the die and container wall (Wick et al., 1984).

Hot working processes have some disadvantages. The high temperatures of hot working may promote undesirable reactions between the metal and its surroundings. Tolerances are poorer due to thermal contractions and warping or distortion can occur due to non-uniform cooling. The metallurgical structure may also be non-uniform, since the final grain size depends on the amount of deformation, the temperature, of the last deformation/recrystallization, etc (Black and Kohser, 2008).

Cold extrusion is the plastic deformation 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). Cold extrusions are concerned with cold forming of rods and bar. It is used for the manufacture of special sections and hollow articles. The material is generally made to flow in the cold condition by the application of high pressure, which forces it through the cavity enclosed between a punch and a die. Cold extrusion can be used with any material that possesses adequate cold work ability e.g. Zinc, copper, aluminum and its alloy. There are various advantages of cold extrusion over the hot extrusion. Some of the important ones include the following (www.industrialmachinery.com): no oxidation process, higher strength due to cold working, good mechanical properties, closer tolerances, good surface finish, lower energy consumption, higher production rates and cleaner environment.

There are tremendous economic benefits derivable from the process of cold extrusion over hot extrusion. Recent advances have expanded the capabilities of manufacturers and a trend toward increased cold working appears likely to continue. According to Black and Kohser (2008), the strength levels induced by strain hardening are often comparable to those produced by the strengthening heat treatments. Even when the precision and surface finish of cold working are not required, it may be cheaper to produce a product by cold working a less expensive alloy (achieving the strength by strain hardening) than by heat treating parts that have been hot formed from a heat treatable alloy. In addition, better and more ductile metals and an improved understanding of plastic flow have done much to reduce the difficulties often experienced during cold forming.

As an added benefit, most cold-working processes eliminate or minimize the production of waste material and need for subsequent machining (a significant feature with today's emphasis on conservation and materials recycling). In the same source, certain factors have been identified as disadvantages of cold extrusion processes. These include; lubrication cost, higher loads are required to initiate and complete deformation, metal surfaces must be clean and scale free, intermediate annealing may be required to compensate for the lost of ductility that accompanies strain hardening.

2.4 Extrusion Equipment

Most extrusions are made with hydraulic presses (Wick et al., 1984) and are classified as vertical or horizontal presses depending upon the direction of travel of the ram.

Vertical extrusion presses are generally built with capacities of 300 to 2000 tons. They have the advantage of easier alignment between the press ram and the tools, higher rate of production and the need of less floor space than horizontal presses.

Horizontal extrusion presses are used for most commercial extrusion of bars and shapes. Presses with capacities of 1500 to 5000 tons are in regular operation, while a few presses of 1400 tons capacity have been used in recent times (Wick et al.,1984).

The basic hydraulic design is the prevalent type used in the aluminium industry; it has a solid ram and is of the simplest construction. They are in many instances designed principally for extruding shapes from solid billets, although they are used also to make seamless tube, using hollow billets and mandrels (Black and Kohser, 2008).

2.4.1 Auxiliary Equipment

Auxiliary equipment for aluminium extrusion include furnaces for billet reheating and die and tool heating; shop facilities for die and tool production, maintenance, and repair; furnaces for heat treatment of extrusions; and saws for cutting extrusions to length

Billet heating could be carried out in conventional gas-fired or oil-fired furnaces. Heating of dies and tools to operating temperatures using furnaces before insertion in the press are advisable because this will extends the life of the tool and avoids the press delays otherwise encountered when employing open-flame heating of tools after assembly in the press (Wick et al., 1984).

2.5 Extrusion Parameters

The extrusion parameters of interest include the following (Wick et al, 1984):

Breakthrough pressure: This is defined, mostly in case of direct extrusion, as the maximum extrusion pressure at which the metal begins to flow through the die. As the billet extrudes through the die, the pressure required to maintain flow progressively decrease with decreasing length of the billet in the container. It is sometime referred to as onset pressure.

Extrusion ratio: It is defined as the ratio of the initial billet cross-sectional area to the final cross-sectional area. It is essentially a measure of the strain which the billet undergoes during the extrusion process.

A large extrusion ratio requires higher pressure from the presses, particularly in case of cold extrusion processes (Wick et al., 1984). It is denoted by R and is given by the expression

$R = A_0/A_f$.. (2.1)

Where

A_o = is the cross-sectional areas of the billet before extrusion

A_f = is the cross sectional area of the billet after extrusion

Fractional reduction in area is given by the following expression (Wick et al., 1984)

$r = 1- A_o/A_f$ ………………………………………………….. (2.2)

Extrusion pressure is given by the definition: the extrusion pressure is directly related to the natural logarithms of the extrusion ratio. Therefore, the extrusion force may be expressed as (Wick et al., 1984)

$P = kA_0 \ln (A_o/A_f)$……………………………………………. (2.3)

Where K = the extrusion constant

2.6 Defects in Extrusion Process

2.6.1. **Surface cracking**; if the extrusion temperature, friction or speeds are too high, surface temperature will rise significantly and can lead to surface cracking and tearing. These cracks are intergranular and are as a result of hot shortness. This can be avoided by using lower temperatures and speeds.

2.6.2 **Extrusion defect**: some types of metal flow tend to draw surface oxides and impurities toward the centre of the billet. This defect is known as extrusion defect or pipe or tailpipe or fishtailing. A considerable portion of the metal can be rendered useless as an extrusion product because of this. This can be reduced by controlling friction and minimizing temperature gradient (Wick et al., 1984)

2.6.3. **Internal cracking** (also known as center burst, centre cracking, arrowhead fracture or chevron cracking). These are internal defect that appear on the longitudinal cross section of the workpiece as arrowhead that point in the direction of metal flow. The major variable influencing this are the die angle, extrusion ratio and friction (Wick et al., 1984). This defect propagates from an internal crack in the billet as a result of tensile stress along the centre line of the workpiece.

2.7 Deformation Efficiency

The deformations efficiency η_{def} is defined as the ratio of the theoretically required ideal work W_{id} and the actual work done, W_{eff} (Lange, 1985)

$$\eta_{def} = W_{id}/W_{eff} \approx F_{id}/F_{eff} \qquad (2.4)$$

Where F_{id} –ideal force and F_{eff} –actual force

2.8 Factors affecting Deformation Efficiency.

The deformation efficiency is affected by the following (Lange, 1985).These include work material, deformation ratio, die opening angle, tool material, lubricant and strain rate.

Normal friction value for extrusion processes are given in Table 2.1

Table 2.1: Normal friction values for extrusion processes

Process	Solid forward extrusion	Hollow forward extrusion
Coefficient of friction μ	0.04 – 0.08	0.1 – 0.125

Source: (Lange, 1985)

2.9 Material Surface Properties

There is a direct relationship between surface properties of the material worked and the lubricant that is applied to a particular surface (Wick et al., 1984). Generally there are many potential advantage of using lubricant in extrusion but little use is made of lubricated extrusion for aluminum and the only lubricant used is normally a token of graphite based grease on the face of the die and of the dummy block or ram (Sheppard, 1989). If too much or too little lubricant is used several defects mostly on the surface occur (Sheppard, 1989).

2.10 Four Categories of Material Surface:

Normal surfaces: most normal surfaces are those that have a natural affinity enabling them to retain lubricant readily. They generally do not require special wetting or polarity agents to obtain sufficient lubrication. The materials are generally clean and free of such contaminant as heavy oxide films and extraneous gases like nitrogen gas e.t.c. They tend to hold lubricant that is applied to them.

Inactive surfaces: an inactive surface is one in which the strength of the bond between the lubricant additive and the metal atom is low. The attractive energy of the metallic surface also is low. This lessens the tendency for chemical reaction with lubricant additives. Aluminum metal is a special case since its active surface is usually coated with an inactive oxide film. It needs a high –film strength lubricant.

Coated surfaces: lubricant used on these coatings must be compatible and clean and must not cause the surface coating to peel, blister, blush or stain.

Active surface: An active surface is one in which the bond strength between the lubricant additive and metal atom is great. The attractive energy of the metallic surface is high. Commonly used as additive for this surface is oleic acid, lard oil and some emulsifiers on materials like brass, aluminum e.t.c. (Sheppard, 1989).

2.11 Aluminium

According to Vargel (2004), the discovery of metallic aluminium is attributed to Sir Humphrey Davy (1778-1829) who used the term "aluminium" in 1809. He obtained an alloy of aluminium with iron, by electrolysis of molten aluminium salts. It was Wohler who, in 1827, succeeded in producing a sufficiently pure metal to determine some of its properties, most notably its low density. Commercial aluminium is made by an electrolytic process from bauxite (a hydrated alumina).

2.11.1 The Metallurgy of Aluminium.

According Encarta dictionary, metallurgy can be defined as the study of the structure and properties of metals, their extraction from the ground, and the procedures for refining, alloying, and making things from them.

The art of the metallurgist is to create alloys from a given base metal, be it copper, iron or aluminium, by adding controlled amounts of other metals (metalloids) in order to improve or modify certain properties such as mechanical properties, formability, weldability, etc. (Vargel,2004). Unalloyed metals generally have only few applications where they exhibit very particular properties, these properties are often limited to a very narrow field of application.

2.11.2 Production of Aluminium

Aluminum ore is called Bauxite, which is a heterogenous mixture of aluminum hydroxide minerals bound in a matrix of clay, silica, silt and other metallic hydroxides. It is usually found near the Earth's surface and so strip-mining and pit mines are the typical methods of extraction (www.rocksandminerals.com/aluminium/production & wikipedia.org/wiki/bauxite).

The production of metallic aluminum requires two steps. First the bauxite ore has to be converted to a mineral called Alumina (aluminum oxide Al_2O_3), by a method called the Bayer process. In this process, the bauxite ore is treated with hot sodium hydroxide solution ($2NaOH + 3H_2O$), which dissolves only the alumina from the bauxite. The process is completed by cooling the "Bayer liquor", drying the residue, and then reheating (calcining) the residue to obtain nearly pure Alumina.

Aluminum metal is obtained by electrolysis of the Alumina using the Hall process (Hall-Héroult process). The alumina is dissolved in liquid

Cryolite (Na_3ALF_6) at a temperature of over 1000^oC, and then a low-voltage high-current electrical field is used to separate the aluminum from the oxygen and Crylolite. The voltage in a Hall cell is only 3-5 volts, but the current is typically 200,000-300,000 amperes. Because the liquid pure aluminum metal is denser than the cryolite, the metal collects at the bottom of the cell where it can be periodically drained out and cooled.

In the early 20th century, over half of the world's bauxite was mined in Arkansas. Now the USA produces virtually no domestic bauxite and is an importer of the ore. Nearly 50% of the Alumina used in the US in 2008 was imported from Australia. Other major sources of bauxite and alumina are Guinea, Jamaica, Brazil, China and India (www.rocksandminerals.com/aluminium/production).

The production of aluminum metal uses a tremendous amount of energy. The recycling of existing aluminum products is the most cost-effective way of obtaining aluminum metal for future use, being far less expensive than processing Bauxite and Alumina.

2.11.3 Advantages of Aluminium

The recent increase of applications for aluminium and its alloys, as well as the sustained rise in consumption can be attributed to several of its properties which are decisive criteria in user’s choice of metals, especially in the fields of transport, building, electrical engineering and packaging. These advantageous properties are (Vargel, 2004): lightness, thermal conductivity, electrical conductivity, suitability for surface treatments, corrosion resistance, diversity of aluminium alloys, diversity of semi-products, functional advantages of extruded and cast semi-products, ease with which aluminium can be formed and recycled.

I. **Lightness**

According to Vargel, (2004), the discoverers of aluminium were particularly impressed by the low density of this metal. Aluminium is much lighter than any other common metal, and the kind of sensation which it gives you to carry the ingot of this metal is always amazing, even if you already know about this peculiar aspect.

Lightness is the property of aluminium that first springs to mind, so much so that for a long time the term “light alloy” was used for what is now called aluminium alloys. Aluminium is the lightest of all common metals. Its density is 2700 $kg.m^{-3}$, which is almost three times less than that of steel. The density of aluminium alloys ranges from 2600 to 2800 $kg.m^{-3}$.

Several areas of technology take advantage of aluminum’s lightness:

- Transport: all airplanes, most vehicles and more recently high speed trains make use of aluminium which leads to a weight saving.
- Mechanical Engineering: aluminium is widely used for moving parts.
- Power Transmission: EC grade aluminium alloy is standard conductor in transmission lines.

II. Thermal Conductivity

Unalloyed aluminium is an excellent heat conductor, with roughly 60% of the thermal conductivity of copper, the optimum performer among common metals. The thermal conductivity of aluminium alloys depends on their composition and metallurgical temper (appendix 3). This property led to replacing tin-plated copper with aluminium alloys in the manufacture of kitchen utensils, both for domestic and professional use (Vergel, 2004).

Whenever there is a problem related to heat exchange, the use of aluminium is always taken into consideration, under the condition, of course, that the medium is appropriate when liquid-liquid or liquid-gaseous exchange is envisioned. There are many applications of aluminium heat-exchangers: cars, commercial vehicles, refrigerators, air conditioning, desalination of seawater, solar energy, coolers in electronic devices, etc.

III. Electrical Conductivity

The electrical conductivity of aluminium is around two-thirds that of copper, which it is replacing in many electrical applications. Overhead power transmission lines made of aluminium or aluminium alloy are used throughout the world. Aluminium bars and tubes are also widely used in connecting stations for high and medium voltage outdoor networks.

IV. Resistance to Corrosion

Aluminium and its alloys are known to have good resistance to atmospheric corrosion. Many decades of experience with its use in buildings, public works, shipbuilding, etc have confirmed the observations of the earlier scientists. This very good resistance to corrosion, as much as lightness, explains the development of numerous aluminium applications and offers users a number of major advantages (Vargel, 2004):

-Equipment and components can have a very long service life. It is not uncommon to find roofing, wall cladding panels, marine installations, ships, etc. with decades of service behind them. This also applies to the field of transport and many other applications.

- Maintenance is minimal, even when no extra protection (painting, anodizing) is provided. When aluminium is painted, replacement of the paint is less frequent and less urgent because the underlying metal generally has good resistance to corrosion.

- Appearance is preserved longer, because of the very good resistance to corrosion. This has become a very strong sales argument, especially for applications where the user wishes to maintain a good surface appearance at the lowest possible cost. Examples are commercial vehicles, outdoor municipal facilities, traffic signs (indicator boards, gantries), etc.

V. Suitability for Surface Treatments

Aluminium surface treatments can serve several purposes. Some of those purposes are as follows (Vargel, 2004):

- Protecting certain alloys if their natural corrosion resistance is deemed insufficient, often the case with copper-containing alloys of the 2000 and 7000 series,
- Preserving the surface aspect , in order to avoid pitting corrosion or blackening,
- Modifying certain surface properties such as superficial hardness, and
- Decorating the metal.

VI. The diversity of Aluminium Alloys

Aluminium alloys are very numerous and offer a wide range of compositions, properties and uses. The continuing progress in the metallurgy of aluminium has produced high performance alloys that are well suited to all types of applications, using conventional or special fabrication techniques among others (Vargel, 2004).

While alloys in the same series share common properties, one series can differ greatly from another, and certain properties can vary widely. Thus, alloys in the 5000 series are weldable and generally have good corrosion resistance, while alloys in the 2000 series have better mechanical properties, but cannot be welded using conventional techniques, and their resistance to atmospheric corrosion is poor.

VII. The Diversity of Semi-products

The transformation techniques of aluminium –rolling, extrusion, and casting present designers and manufacturers with a very wide range of semi-products such as castings, rolled products, extrusions and die-forged or hand-forged products.

Several alloys are compatible for welding purposes. Rolled or extruded semi-products of the 3000, 5000 and 6000 series can be joined with castings in the alloys 42100 (A-S7G03), 42200 (A-S7G06), 43000 (A-S10G) and 71000 (A-Z5G) by means of TIG and MIG welding. This diversity of semi-products makes it possible to select the right location for stresses on components of bolted or welded structures, simplify finishing processes by using coil-coated or preanodised sheet and save on the time needed for assembly.

VIII. The Functionality of Castings and Extrusions

Casting makes it possible to manufacture pieces with complex shapes and several functions, reducing complex machining to simple machining or surface milling.Extrusion allows manufacturing profiles with a very wide range of dimensions and shapes, profiles that are suited to the needs of designers who need to select the right location for stresses on structures. Extrusion dies are normally easy to manufacture at a moderate cost.

IX. The Ease of Use

Provided that certain rules specific to aluminium alloys are observed, aluminium alloys can be processed using the same conventional techniques of shaping, bending, fabrication, deep drawing and machining as used for other common metals such as mild or stainless steel. Aluminium alloys can usually be processed without the need for specific equipment or machine tools. It is advisable to set up a workshop dedicated to aluminium alloy processing. Like all other common metals, aluminium alloys lend themselves to joining techniques such as

- Welding
- Bolting
- Riveting
- Clinching
- Adhesive bonding, and
- Brazing.

X. Recycling

Aluminium recycling is very attractive, both in the context of energy savings and for economic reasons. Aluminium remelting requires only 5% of the energy that is needed to extract the metal from its ore (Vargel, 2004). Available evidence on scrap collection have shown that aluminium scrap always has a higher value than steels scrap (Gronostajski, et al., 2000). Also significant is the steady rise in the consumption of recycled metal over the years.

2.11.4 Physical Properties of Aluminum.

The physical properties of unalloyed aluminium are listed in Table 2.2 and appendices 3 & 4.

Table 2.2: Physical Properties of Unalloyed Aluminium.

Property	Unit	Value	Remarks
Atomic number		13	
Density, ρ	$kg.m^{-3}$	2698	
Melting point	^{0}C	660.45	$<1013\times10^{-3}$bar
Boiling point	^{0}C	2056	$<1013\times10^{-3}$bar
Vapour pressure	Pa	3.7×10^{-3}	at $927^{0}C$
Mass internal energy, u	$j.kg^{-1}$	3.98×10^{5}	
Mass internal capacity, C_p	$j.kg^{-1}k^{-1}$	897	at $25^{0}C$
Thermal conductivity, λ	$W.m^{-1}K^{-1}$	237	at $27^{0}C$
Linear expansion coefficient, α	$10^{-6}k^{-1}$	23.1	at $25^{0}C$
Electrical resistivity, ρ	$10^{-6}\Omega.m$	26.548	at $25^{0}C$
Magnetic susceptibility, k		0.6×10^{-3}	at $25^{0}C$
Longitudinal elasticity modulus, E	MPa	69000	
Poisson's ratio, v		0.33	

(Source : Vargel, 2004)

2.12 Lubrication and Lubricants in Metal Forming

Lubrication primarily concerns modifying friction and reducing wear and damage at the surface contacts of solids rubbing against one another. Anything introduced between the surfaces to accomplish this is a lubricant.

2.12.1 Lubrication in Metal Working Processes

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)

A Lubricant's main function is to minimize surface contact between the tooling and workpiece. If too much surface contact occurs, metal pick up on the tooling can damage the product and cause high maintenance costs from excessive tool wear. If friction is too high, temperature can exceed material limits and reduce production speeds. Workpiece surface quality is directly related to the properties and behavior of lubricants, whether surface contact occurs or not. In general, the lubrication functions influence workpiece quality, process productivity and cost.

In discussing lubrication for metal forming process it is useful to distinguish between the different modes or regimes that can occur. The main variable to be considered is the thickness of the lubrication film interposed between the surfaces. The four regimes of lubrication are (Sheppard, 1989):

(a) Thick – film lubrication:

In thick film lubrication, the film minimum thickness is large compared with either the molecular size of the lubrication or the surface roughness of the tooling or workpiece. Thus the lubrication may be regarded as a continuum (liquid or solid) between smooth surfaces.

The tool and workpiece surfaces are completely separated by the lubrication film. For conventional extrusion, thick film lubrication has potential advantage because 30 – 40% of the total extrusion force is expended in overcoming friction (Sheppard, 1989).

(b) Thin – film lubrication

If the minimum thickness of lubrication film is reduced or if surface roughness is increased, the system may enter the thin film lubrication regime. In this mode, the minimum film thickness is of the same order as the surface roughness, but it is still much larger than the molecular size of the lubrication. Under these circumstances the lubrication may be treated as a continuum but roughness of the surface must be considered in the analysis. Because of their high speed requirement, cold rolled and high speed wire drawings are among the relatively few metal working processes for this mode of lubrication.

(c) Mixed – film lubrication

Further reduction in the minimum film thickness results in potential contact between roughness peaks (asperities). The lubrication however contains materials that react chemically with the surfaces, forming highly adhering boundary films with a thickness in the order of the lubricant molecular size. These films prevent direct metal-to-metal contact between asperities. Part of the load between the surfaces is carried by the thin boundary film in the roughness valleys and part is carried by the thin boundary films over the peaks. This results in the mixed-film lubrication regimes.

d) Boundary film lubrication

The final lubrication regime of importance in metal forming is boundary film lubrication. This is purely a boundary-film lubrication regime in which the entire load between the surfaces is carried on thin boundary films on the asperity peaks. The coefficient of friction is usually in the range of 0.1 to 0.3 (Lange, 1985).

For most practical metal forming processes, determining and identifying the lubrication regime is difficult. It is also equally difficult to assess accurate values of friction for most processes. The use of constant coefficient of friction is not appropriate. In most processes, lubrication is a combination of all the possible regimes and thus friction varies during deformation (Wick et al., 1984).

2.12.3 Basic Requirements of a Lubricant in Metal Working

Lubricants should meet some basic requirements for metal working. These requirements include the following: it must withstand the working pressure and temperature, must not deteriorate in service and storage, must be easy to apply and remove and, not leave an objectionable residue, and must be safe, non-toxic and not otherwise objectionable for use.

Lubrication primarily concerns modifying friction and reducing wear and damage at the surface contacts of solids rubbing against one another. Anything introduced between the surfaces to accomplice this is a lubricant.

2.13 Types of Lubricants

Lubricants can be liquids, solids or even gases, and they are most often oils or greases. Lubricants are selected according to the need of the particular application. Careful lubricant selection helps obtain improved performance, lower operating cost, and longer service life, both for the lubricant and the equipment involved (Eugene and Theodore, 1996).

2.13.1 Solid Lubricant

It is defined as any material used as a thin film or a powder during relative movement and to reduce friction and wear. Solid lubricants are materials with low coefficients of friction compared to metals, and they are used to reduce friction and wear in a variety of applications.

Graphite is most common solid lubricant used, and others include molybdenum disulphide, polytetrafluoroethylene, talc, graphite fluoride, polymers, and certain metal salts (Eugene and Theodore, 1996). The desire for lubricants to operate at extremes of temperature and environment beyond the range of organic fluids has spurred research and development of solid lubricants. The performance of solid lubricant films is influence by the solid lubricant used, the method of application, the bearing surface, material finish and its hardness (Eugene and Theodore, 1996).

Solid lubricants could be either organic or inorganic. There are three general kinds of inorganic compounds that serve as solid lubricants (Miyoshi, 1998):

i. Layer- lattice solids: materials such as graphite and molybdenum disulphide have a crystal lattice structure arranged in layers.
ii. Miscellaneous soft solids: e.g. lime, talc, white lead, bentonite are used as lubricants.
iii. Chemical conversion coatings: the best known lubricating coatings are sulfide, chloride, oxide, phosphate and oxalate films.

Solid organic lubricants are usually divided into two broad classes:

i. Soaps, waxes and fats: this class includes metallic soaps of calcium, sodium, lithium, animal waxes, fatty acids and fatty esters.
ii. Polymeric films: these are synthetic substances such as Teflon.

2.13.2 Properties of Solid lubricants

The properties which are important in determining the suitability of a material for use as a solid Lubricant include (Marth, 2000):

i. Crystal structure

Solid lubricants such as graphite and molybdenum disulphide (MoS) possess a lamellar crystal structure with inherently low shear strength.

ii. Thermal stability

Thermal stability is very important. One of the most significant uses for solid lubricants is in high temperature applications not tolerated by other lubricants. Good thermal stability ensures that the solid lubricant will not undergo undesirable phase or structural changes at high or low temperature extremes.

iii. Oxidation stability

This is another very important factor. The lubricant should not undergo undesirable oxidation changes when used within the applicable temperature range.

iv. Volatility:

The lubricant should have a low vapour pressure for the expected application at extreme temperatures and in low pressure conditions.

v. Mobility

The life of solid films can only be maintained if the film remains intact. Mobility of adsorbates on the surfaces promotes self-heating and prolongs the endurance of films.

vi. Melting point

If the melting point is exceeded, the atomic bonds that maintain the molecular structure are destroyed, rendering the lubricant ineffective.

vii. Hardness

A maximum hardness of '5' on the Moh's scale appears to be the practical limit for solid lubricants.

viii. Electrical conductivity

Certain applications such as sliding electric contacts require high electrical conductivity while other applications such as insulators making rubbing contact, require low conductivity.

2.13.3 Conditions requiring use of Solid Lubricant

The most common conditions requiring the use of solid lubricants are:

1. Extreme temperature and pressure conditions

These are defined as high temperature applications up to 1926°C (3500°F) where other lubricants are prone to degradation or decomposition, extremely low temperatures, down to -212°C (-350°F) where lubricants may solidify or congeal.

2. As Additives

Graphite, molybdenum disulphide and zinc oxide are frequently added to fluids and greases (Marth, 2000).

3. Intermittent Loading Conditions

When equipment is stored or is idled for prolonged periods, solid provide permanent, non-corrosive lubrication.

4. Environmental conditions

Solid lubricants are effective in applications where the lubricated equipment is immersed in water that may be polluted by other lubricants such oils.

2.13.4 Advantages of Solid Lubricant

1. More effective than fluid lubricants at high loads and speeds.
2. High resistance to deterioration in storage.
3. Highly stable in extreme temperature, pressure, radiation and reactive environments.

2.13.5 Disadvantages of Solid Lubricant

1. Poor self-healing properties. A broken solid film tends to shorten the useful life of the lubricant.
2. Poor heat dissipation.
3. Colour associated with solids may be undesirable.

2.13.6 Dispersion of Powdered Solids

Dispersions are mixtures of solid lubricant in grease or fluid lubricants. The most common solids used are graphite and molybdenum disulfide (MoS) (Marth, 2000). The fluid provides normal lubrication while the solid lubricant increases lubricity and provides extreme pressure protection.

Graphite as reported is frequently added to fluids and greases as additives. Soft metal films are used in lubrication due to its low shear strength, good adhesion to the base, reduced adhesion to the die and improved reactivity with the lubricant (Lange, 1985).

Natural oils, fats, waxes of animals or vegetable origin offer a wide range of viscosities, relatively low solidification pressures and usually contain some boundary agents (Carsson, 2009 and Lange, 1985). They can be used as complete lubricants on their own, if they satisfy the required conditions.

2.13.7 Graphite

Graphite occurs naturally in flakes in metamorphosed rocks rich in carbon, but it can also be found in veins and in pegmatites. Where large deposits are found it is mined and used as an industrial lubricant and for 'lead' in pencils. It has high thermal stability and chemically inert. It is an opaque material and has a density of 2.09 – 2.23g/cm^3 (www.mindat.org/graphite). Graphite occurs naturally in Gayama village of Taraba State, North-eastern Nigeria. The village is about 289km from the state capital, Jalingo.

2.13.8 Physical Properties of Graphite

Lustre: sub-metallic
Diaphaneity: opaque
Colour: Iron black to steel-gray
Streak: black to steel gray
Hardness (Moh's): 1-2
Hardness (Vickers): VHN_{10} =7-11kg/mm^2
Tenacity: Flexible
Cleavage: Perfect {0001}
Density (measured): 2.09-2.23g/cm^3
Density (calculated): 2.26g/cm^3

(Source:www.mindat.org/graphite)

2.13.9 Crystallography of Graphite

Crystal System: Hexagonal
Class (H-M): 6mm-Dihexagonal pyramidal
Space Group: $P6_3mc$
Cell Parameters: a=2.461A, c=6.708A
Ratio: a:c=1:726
Morphology: Hexagonal platy crystal
(Source:www.mindat.org/graphite)

2.13.10 Liquid Lubricants

A variety of liquids are used as lubricant for metal deformation processes which include (Wick et al., 1984):

1. Mineral oils. The viscosities of mineral oils used in metal working range from that of kerosene to that of very heavy oils such as asphaltic residues which are apparent solids. The high viscosity mineral oils show appreciable boundary lubrication ability.

2. Natural oils. Palm oil, rape seed oils, lard oils and other natural oils are used in metal forming. Natural oils are most effective in the boundary regime than are mineral oils because they contain free fatty acids which can form boundary films.

3. Synthetic oils. Synthetic oils are usually pure chemical species. They are used in metal forming processes because they are more resistant to degradation at high temperatures than are mineral oils.

4. Compounded oils. Compounded oils represent mixtures of mineral or synthetic oils containing “oiliness” agents (fatty oils or fatty acids) and other additives. They are used extensively in metal forming.

5. Extreme pressure oils. They are used for operations requiring good antiweld properties. These are oils containing highly active chemical compounds in additive concentrations. For example, sulphur may be dissolved in a mineral oil or fatty oil.

6. Emulsions. These “soluble oils” usually are compounded oil or EP oil containing an emulsifier that requires little energy to disperse in water to form a stable emulsion.

7. Solutions. Mixtures of water with other fluids or additives. Water solutions are used in metal deformation processes. They are usually

concentrated aqueous solutions of inorganic salts (such as sodium nitrate or borate), water soluble detergents and amines.

2.13.11 Castor Oil

Castor oil also known as ricinus oil is a triglyceride of fatty acids, which occurs in the seed of the castor plant which has the botanical name Ricinus communis of the family Eurphorbiacae (Ogunniyi, 2005). It is a vegetable oil obtained from the castor plant seed which are grown in the wild in large quantities in most tropical and sub-tropical countries. It is available at low cost. The castor seed is pressure squeezed to extract the oil neatly to avoid contamination. Local extraction method is now seldom use due to the fact that only certain percentage of the oil is usually extracted and the cake thrown away.

Castor oil consists almost entirely of the triglycerides ricinoleic acid. It is a colourless to very pale yellow liquid with mild or no odour or taste. Its boiling point is 313^{o}C and its density is 961kg/m^{3}. It is extracted by either pressing or solvent extraction. Castor oil is unique among all fats and oils in that: it is a source of an 18-carbon hydroxylated fatty acid with one double bond, it is a triglyceride in which 90% of the fatty acid chains are ricinoleic acid, and it is a non-toxic, biodegradable and renewable resource. (Castor oil-Wikipedia, the free encyclopedia).

2.13.12 Characteristics of Castor Oil

Castor oil consists almost entirely of triglycerides ricinoleic acid.

- It ranges in colour from colourless to greenish.
- It is viscous liquid.
- It is non-drying.
- It has a faint but characteristic odour.
- It has a slightly acid taste.

Many derivatives can be produced which have a similar chemical composition to petroleum based oils (Castor oil-Wikipedia, the free encyclopedia).

Castor oil, like any other vegetable oils, has different physical and chemical properties that vary with the method of extraction (Ogunniyi, 2005). Cold-pressed castor oil has low acid value, low iodine value and it is lighter in colour. Typical properties of castor oil are presented in Table 2.3 (Ogunniyi, 2005).

Table 2.3: characteristics of castor oil grade

properties	cold pressed	dehydrated
specific gravity	0.961-0.963	0.926-0.937
Acid value	3	6
Iodine value	82-88	125-145000
Saponification value	179-185	185-188

Source: (Ogunniyi, 2005)

Equations showing the constitution of castor oil are presented below:

$$\begin{array}{lcl} \mathbf{CH_2\text{-}O\text{-}C(O)\text{-}R} & & \mathbf{CH_2\text{-}O\text{-}C(O)\text{-}R} \\ \mathbf{CH\text{-}O\text{-}C(O)\text{-}R} & + & \mathbf{CH\text{-}O\text{-}C(O)\text{-}R} \\ \mathbf{CH_2\text{-}O\text{-}C(O)\text{-}R} & & \mathbf{CH_2\text{-}O\text{-}C(O)\text{-}R^1} \end{array}$$

$R=-(CH_2)_7-CH=CH-CH_2-CH(OH)-(CH2)_5-CH_3$

R^1=Other fatty acid derivatives

There are many uses for castor oil and its derivatives. Some of these include plastic, cosmetics and hair oils, adhesives, synthetic resins, soaps, greases and lubricants, and drying oils (Ogunniyi, 2005).

2.14 Viscosity of Oils

Viscosity is a measurement of a fluids resistance to pouring. Thick liquids are said to have a high viscosity and thin liquids, a low viscosity. Viscosity can be altered by a change in temperature (Kulkarni, et al., 2003).

In order to maintain efficient lubrication at the working temperature range, the viscosity of lubrication oil must have minimum value at that temperature (Kulkarni and sawant, 2003). Viscosity is therefore the most important property to consider in choosing a lubricant for a given application.

The old viscosity test methods practiced in the United States described and measured the viscosity of most industrial lubricants in either saybolt universal seconds (sus) or centistokes (cSt) at reference temperatures of 100^oF (37.8^oC) and 210^oF (98.9^oC) (Marth, 2000). But most petroleum testing laboratories now measure the viscosity in centistokes (cSt) at 40^oC

and 100^{o}C according to ASTM D445, the method specified by the International Standards Organization (ISO).

The viscosity of castor oil measured in centistokes as obtained at 37.8^{o}C was 259cst (www.castrol.com/viscosity.htm).

2.15 Viscosity Index

Viscosity index is an entirely empirical parameter that compares the kinematic viscosity of the oil of interest to the viscosities of two reference oils that have a considerable difference in sensitivity of viscosity to temperature. The reference oils have to be selected in such a way that one has a viscosity index equal to one hundred (VI = 100) at 100^{o}F (37.8^{o}C), but they both have the same viscosity as the oil of interest at 210^{o}F (98.89^{o}C) as illustrated below (Stachowiak and Batchelow, 2005).

The viscosity index VI can be calculated from the following formula (Stachowiak and batchelow, 2005).

$$VI = {(L-U)}\big/{(L-H)} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. 2.5$$

Firstly, the kinematic viscosity of the oil of interest is measured at 40^{o}C ('U') and at 100^{o}C. Then the values of 'L' and 'H' that correspond to the viscosity at 100^{o}C of the oil of interest are read from ASTM D2270 Table. Substituting the obtained values of 'U', 'L' and 'H' into the above equation yields the viscosity index.

Viscosity index VI can be classified as follows (www.engineersedge.com, 2000).

Low VI – below 35;

Medium VI – 35 – 80;

High VI – 80 – 110;

Very high VI – above 110

Therefore, a fluid that has a high viscosity index can be expected to undergo very little change in viscosity with temperature extremes and is considered to have a stable viscosity.

2.16 Definition of some Tribological Properties of Lubricant

The significant lubricating fluid properties are: kinematic viscosity, specific heat capacity, density, flash point, pour point, specific gravity, and total base number (NIS draft 1995).

i. Kinematic viscosity (cSt): It is a measure of the lubricant resistance to flow under gravity at a specific temperature. It indicates the thickness or thinness of an oil at a given temperature.

ii. Pour point: It is the lowest temperature at which the oil will flow when cooled under conditions prescribed in Nigeria industrial standard (NIS draft, 1995).

iii. Specific gravity: This is the ratio of the weight of a given volume of lubricant at 15^0C, to the weight of an equal volume of distilled water at 4^0C temperature.

iv. Specific heat capacity: Specific heat capacity of a liquid is defined as the heat required to raise unit mass of substance by one degree of temperature. This can be stated by the following equation

$\Delta Q = mc\Delta T$…………………………………………… 2.6

Where Q=Heat supplied to the substance

m=mass of the substance

c=specific heat capacity

T=temperature rise.

The heat capacities belong to the basic thermo-physical and thermodynamic properties which characterizes a liquid (Abere and Adeyemi, 2008). So heat capacity of an oil plays very important role especially when an oil is used to remove heat.

v. Density: Density of a material is defined as its mass per unit volume. The symbol most often used for density is ρ. Density is a physical property of matter, as each element and compound has a unique density associated with it.

The density can be expressed as

$$\rho = m/v \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad 2.7$$

Where $A = area\ (\pi r^2)$

ρ =density (kg/m^3)

M =mass (kg)

V =volume (m^3)

The higher the density, the tighter the particles are parked inside the substance. Density is a physical property, constant at a given temperature and density can help to identify a substance.

vi. Specific gravity (SG): Specific gravity is a dimensionless unit defined as the ratio of density of the material to the density of water at a specified temperature. Specific gravity can be expressed as

$$SG = \rho / \rho_{H_2 0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.8$$

ρ = density of the material

$\rho_{H_2 0}$ = density of water

vii. Flash point: Flash point of an oil is the temperature to which an oil has to be heated until sufficient flammable vapour is driven off to flash when brought into momentary contact with a flame. Flash point is clearly related to safety. It is an indication of the combustibility of the vapour of a lubricant. It is also useful in determining fire hazards (Halling, 1987 and herguth, 2000).

viii. pH value: pH of a solution is the measurement of acidity or alkalinity of a solution. The pH of water is 7; hydrochloric acid is 0.00 while that of sodium hydroxide is 14. Lower numbers indicates acidity and higher numbers indicates alkalinity (Encarta Encyclopedia, 2009). The pH values of selected substance are shown in appendix 2.

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Materials

The materials used for the evaluation of the effect of castor oil-graphite lubricant on the extrusion pressure of Aluminium alloy are as described below:

3.1.1 Aluminum alloy bar.

Aluminium alloy 1350 (EC Grade) scrap in the form of a round solid bar, was obtained from Power Holding Company of Nigeria (PHCN) Transmission works centre, Yola, Adamawa State. This grade of aluminium is used in the electrical industries for transmission and distribution purposes. The composition of the Aluminium alloy is presented in table 3.1.

Table 3.1: Chemical composition of 1350 Al alloy

Composition	Al	Si	Fe
Percent(% by weight)	99.5	0.10	0.40

Source; (Brandes and Brook, 1992)

The mechanical properties of the aluminium alloy presented in Table 3.1 are: Tensile strength: 8.5ksi and Yield strength: 3.5ksi.

Aluminium alloy (EC Grade) has been known to be the extrusion class with good extrudability, strength, corrosion resistance, weldability and formability. Aluminum alloy is a proven construction material for vehicles, home appliances and products, both as a framing and cladding material. In the building industry, it is the common material used for window and door joinery and shop fronts. It is widely used in every aspect of the transport, leisure, boating and household appliances industries.

3.1.2 Graphite powder

Graphite powder was used as a dry lubricant which is due largely to the loose interlamellar coupling between sheets in the structure (Lange, 1985).

500g of the graphite powder which has been pulverized to the finest particle size in accordance with ASTM D1514-01 standard test method was obtained for the purpose of this work from Northern Scientific Laboratory, Jimeta Yola, Adamawa State, North-eastern Nigeria .

3.1.3 Castor Oil

Cold pressed castor oil was used in this work because it has low acid value, low iodine value and lighter in color. 200ml of cold pressed castor oil was obtained from Affcot Oil Mill along Numan road, Yola, Adamawa State.

3.1.4 Petroleum Based Lubricant.

The petroleum based lubricant mostly used in Nigeria was taken as standard reference lubricant in this investigation. 100ml of the lubricant was obtained from Towers Aluminum Extrusion Division, Dopemu, Lagos.

3.2 Methods

3.2.1 Procedure for the Formulation of Graphite-Castor Oil Lubricant

Major properties of the lubricant sample were considered for investigation at constant atmospheric pressure. These include density, viscosity, flash point, specific gravity and specific heat capacity. Experimental evaluation of these properties was carried out within the temperature range of 28-100 ^{0}C.

The formulation of the lubricants was based on proportion that would give an optimum result. According to Lange (1985), too much lubricant on the surfaces may cause some defects and the die surface must be clean. The percentage composition of each samples are shown in Table 3.2. The mixture was heated by a heating mantle fitted with temperature controls.

Table 3.2: Composition of the lubricant samples (percentage by weight).

Lubricant	Graphite (w/w %)	Castor oil (w/w %)
Sample A	10	90
Sample B	15	85
Sample C	20	80
Sample D	25	75
Sample E	30	70

The castor oil was mixed with powdered graphite in the weight percent ratio starting with 10% by weight of graphite up to 30% at an incremental interval of 5%. The mixture was tested on the extrusion rig for the extrusion of aluminum alloy. The combination of castor oil was done taking cognizance of their viscosity and flash point as well as their viscosity index. The mixtures reference temperature was ambient (38.5^{o}C).

3.2.2 Procedure to Determine the Melting Point of the Aluminium.

The Aluminium alloy was cut into smaller sizes and melted in Morgan Crucible Furnace of Metallurgy laboratory of Mechanical Engineering Department, Modibbo Adama University of Technology, Yola. Adamawa State, using Kobold TD 1200 thermocouple from Chemical Engineering

Department of the same University. The specimen melting point was determined by taking the temperature reading of the melt, after every two seconds as the melt cools and results recorded.

The aluminium specimens were produced by sand casting because of low cost, simplicity and practically no limit to size or shape. The obtained billets were machined to rod of 14mm diameter and 30mm length using universal lathe machine in the Centre for Equipment Maintenance and Industrial Training of Modibbo Adama University of Technology Yola. Initially, the specimens were heated in an electric furnace to 160^0C for duration of 1hour only in accordance with Onawola and Adeyemi (2002).

3.2.3 Tribological properties test procedure of the formulated lubricant

The lubricant sample was investigated for its tribological properties such as viscosity, flash point, pour point, specific gravity, density, pH value, specific heat capacity.

i. Determination of viscosity

This experiment was carried out in Chemical Engineering Laboratory of Modibbo Adama University of Technology Yola, Adamawa State. The apparatus used for the experiment were rotational viscometer (Visco star plus L) model No:VSCL110458, 50ml beaker, stirrer, and a thermometer. The apparatus was set up as shown on plate 3.1

Plate 3.1 rotational viscometer

The specific procedure that was followed in determining the kinematic viscosity in accordance with ASTM D-445 test method include:

1- a sample lubricant was prepared and put in a beaker with a stirrer.
2- the viscometer was switched on and the measuring configuration was selected.
3- the temperature was noted at 28.5^0C.
4- the time was set to 30 seconds.
5- the spindle value was selected in the sub-menu.
6- the field was selected using the TAB soft key.
7- the viscometer was started using "ON" button.
8- the spindle started moving and viscosity of the sample lubricant was displayed after every revolution of the spindle. These data were updated constantly.
9- the data were recorded and presented.

ii. Determination of specific heat capacity

The method of mixtures was employed for the determination of specific heat capacity of the lubricant samples in Metallurgy Laboratory of Mechanical Engineering Department, Modibbo Adama University of Technology, Yola. Adamawa State. Apparatus include: well-lagged calorimeter with a stirrer, thermometer, heating furnace and electronic balance.

Specific heat capacity was determined as follows:
A rectangular brass of mass 90g was obtained from the metallurgy laboratory. The procedures to determine the specific heat capacity were as follows: The initial temperature of substance was obtained and recorded. The mass of substance was obtained and recorded. Solid Brass was heated using metallurgical heating furnace at 100 ^{o}C for 45 minutes. Experimental apparatus was set up with the lubricant sample under test. Heated solid was transferred to the experiment set up. The rise in temperature of lubricant sample was studied and recorded as the change in temperature occurs until such a time it is no longer rises. Some precautions were taken during the experiment to minimize heat losses to the surroundings.

1. The calorimeter was well lagged.
2. The hot solid was transferred quickly to the calorimeter while stirring gently.

iii. Determination of pH value.

The apparatus consist of the potable pH meter (Extech), 50ml beaker, acidic buffer of pH 4, alkaline buffer of pH 9, Distilled water and organic solvent. This test was conducted in Chemistry Department of Modibbo Adama University of Technology Yola, Adamawa State. The procedure followed include: The pH meter was standardized using acidic buffers of pH 4 and alkaline buffers 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 30^{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 is reported as the pH value.

iv. Determination of flash point

The flash point was determined in the laboratory of Yola NNPC depot using the following procedure in accordance with ASTM D93 standard test method for flash point using manual pensky martens closed cup flash point tester (model 13661-3) shown in plate 3.2.

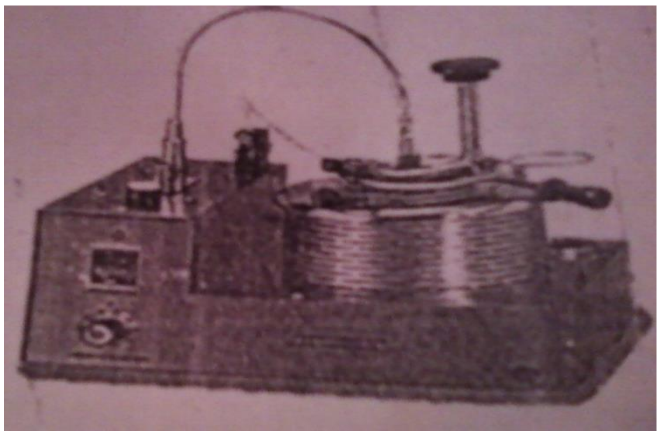

Plate 3.2: Manual Pensky Martens closed cup flash point tester.

The procedure adopted was as follows::

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 cup was located by the three guide pegs so that the handle points the front hand corner.

The lid was filled properly.

The shutter activation shaft was placed on to the lid while engaging the tap with the shutter.

The correct thermometer was inserted into the thermometer port on the lid.

The flexi drive was held well.

It was done in this order; the large end into the stir drive chuck when the smaller end into the square socket on the stirrer. All the drive components were slightly rotated to be aligned properly.

Stirrer speed was selected according to the method 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 and test adjuster screw was closed until their 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 in temperature, the stirrer is stopped and the test flame was dipped into the cup by rotating the stirrer activator knob clockwise to the stop so that the aperture is fully opened. At every dipping, it was observed whether flash has occurred.

Heating was continued and manual dipping procedure was continued according to the test method until flash point was obtained.

At this point, the instrument was turned off and cooling air supply was turned on.

3.2.4 Description of Procedure to Determine Extrusion Pressure

A 25 ton hydraulic press was designed and constructed for use in extrusion of aluminium alloy. It consists of a container to receive the workpiece, a tool carrier for housing the die and support tooling and a ram that applies the extrusion pressure (appendix 1). The experiment was performed on a flat die fabricated from H13 tool steel and case hardened to harden the surface according to industrial standard for extrusion dies.

The conventional process of direct extrusion method was adopted in which the billet moves relative to the container wall. Since the work involved only cold extrusion process, it was carried out below the recrystallization temperature of aluminium alloy 1350 whose melting point was determined as 634 ^{o}C.

The pressure was applied through the ram, which exerts force on the billet causing it to move forward initiating the extrusion through the die. 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 extrusion process, the pressure on the billet increase 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 decreases. The maximum pressure recorded at the start of the extrusion process was referred to in this work as ‘onset pressure’ (Breakthrough pressure) while the one required to maintain flow of the billet through the die was termed final pressure.

The billets were heated not higher than one third (1/3) of the melting point of the specimens. Each sample was heated to the same range of temperature in an oven. The lubricant was applied by hand using brush due to suitability of the application 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. A solid cylindrical aluminum alloy bar was extruded using the rig (appendix 1). Specimens were heated to 160^{o}C which is below recrystallization temperature as the case with cold extrusion practice.

The specimens were extruded using the formulated lubricants of varied ratio of graphite to castor oil. The ratio of castor oil to graphite powder in the formulated lubricant was between 90%:10% and 70%:30% by weight. The extrusion was done through a die of constant diameter of 12.5mm (i.e. constant extrusion ratio).

The samples of the formulated lubricant were used at regular percent interval in evaluating the effect on the extrusion pressure of aluminum alloy rod. The tests were replicated for each 5% increment of percentage by weight of graphite to that of the base oil (Castor oil). Aluminium alloy specimens were also extruded using the standard extrusion lubricant obtained from Towers aluminium extrusion division at Dopemu, Lagos and the both the ‘onset’ and ‘final’ pressures were determined. In extrusion process, temperature is the most important factor to consider. Temperature is most critical because it gives aluminium desired characteristics such as hardness and surface finish (Eugene and Theodore, 1996). Each of the lubricant samples was tested five (5) times on each aluminium specimens at a constant extrusion ratio of 1.12. The extrusion pressures were recorded for each test as described above. The extrusion was also carried out without lubricant and all results are presented in tables and graphs where applicable.

The Aluminium specimens are of the following dimensions: length- 30mm; billet diameter- 14mm and extrusion diameter- 12.5mm.

3.2.5 Procedure for microscopic examination

The microstructure of Aluminium specimens at pre and post extrusion was examined using Accuscope microscope fitted with a camera (serial No.0524011) in materials science laboratory of Obafemi Awolowo University, Ife, Osun state using the following procedure: the sample was first cut out to the length of 4mm and diameter of 12.5mm, and then mounted. The main purpose of mounting is to be able to hold the material. It is usually done when the material is small. The specimen was subjected to grinding. Grinding of the sample was done manually from the most coarse grid paper to the finest paper. Water was used during the grinding to clean the particles. After grinding, the sample underwent polishing. Emery cloth was used. The cloth was dry so it was first made wet with water after placing it on the machine. A solution of silicon carbide (SiC) was poured on the cloth. It was followed by etching. Cutting bud was dipped into 2 gram of sodium hydroxide pellets plus 98% water and was used to swap the surface. Then the samples were ready for microscopic examination. The samples were then viewed through the microscope starting from the lower magnification and their internal structure was seen.

3.2.6 Hardness test

Hardness properties of the extruded aluminium product were carried out on Brinell hardness machine in Material Science Laboratory of OAU Ife, Osun State. These tests were conducted around the transverse section using Brinell hardness testing machine. Four different aluminium specimens were tested. They were labeled A, B, C & D. The average hardness for each extruded product under different extrusion variables was determined and recorded.

CHAPTER FOUR

3.0 RESULTS AND DISCUSSION

4.1 Results

4.1.1 Aluminium alloy specimen melting point

The melting point of the cast Aluminium alloy (EC Grade) specimens used for this investigation was determined as described. The melting point obtained was 634^{o}C using the cooling curve graph in figure 4.1. This shows low level of impurities as compared to the actual melting point of 646^{o}C. The cooling curve is presented in figure 4.1.

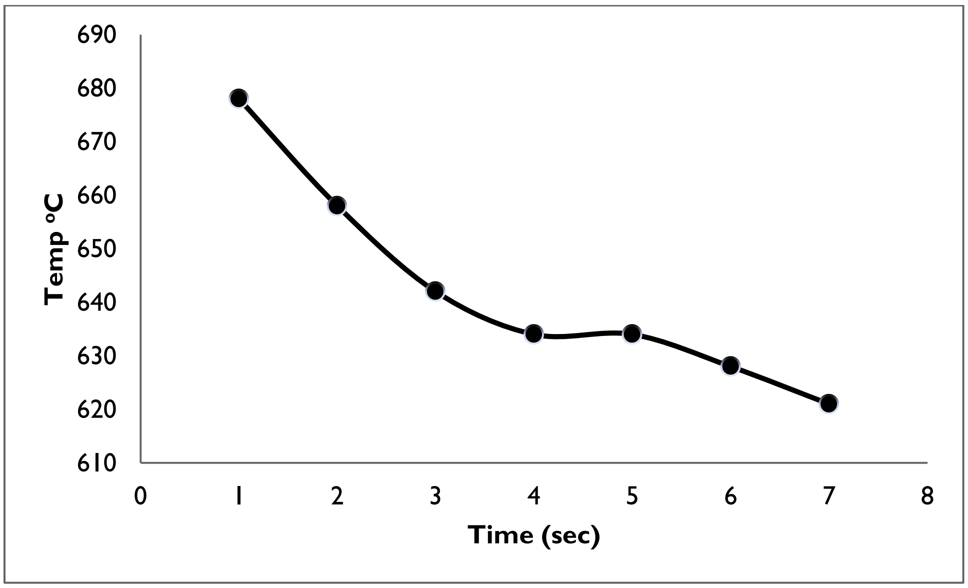

Figure 4.2: Cooling Curve of Aluminium Alloy (EC Grade)

4.1.2 The tribological properties for the formulated lubricant

Lubricant sample B was the one that produced the lowest pressure during the experiment and so it was considered for the tribological properties tests. Since one of the objectives of this project was to provide an alternative to the existing extrusion lubricant.

4.1.3 Density of lubricant sample B.

The five different readings for the volume of the lubricant sample measured at constant temperature of 29 ^{o}C are presented in Table 4.1. To determine the average density of the lubricant sample, the following values were obtained:

Mass of sample;40g.
Volume of sample;43cm^3

Density = $\frac{Mass}{Volume}$

= 0.93g/cm^3

≈930kg/m^3 .

Table 4.1: Mass and volume of lubricant sample measured at 29 ^{0}C

Sample	Mass (g)	Volume (cm^3)
1	40	44
2	40	43.5
3	40	43.5
4	40	42.5
5	40	42
Average	**39.8**	**43.1**

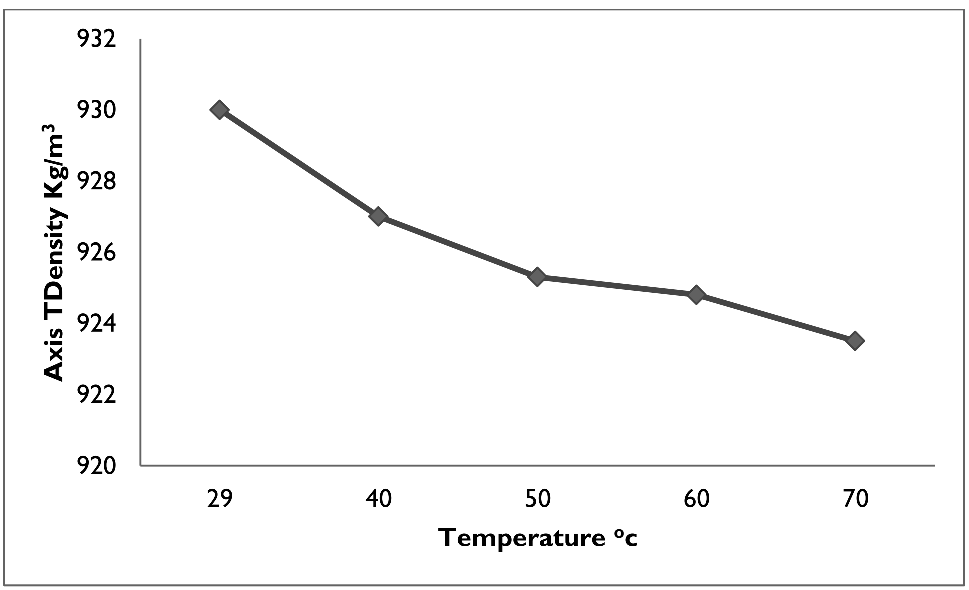

Figure 4.2: Variation of density of the lubricant sample with temperature.

4.1.4 Viscosity of lubricant sample B

The viscosity readings of the lubricant sample at maximum and minimum points as obtained are presented in Tables 4.2 and 4.3 respectively.

Table 4.2: Viscosity of lubricant sample at minimum value

Sample	Viscosity (cP)
1	0.9810
2	0.9815
3	0.9805
4	0.9805
5	0.9804
Average	0.9808

Table 4.3: Viscosity of the lubricant sample taken at maximum values

Sample	Viscosity (cP)
1	1.0215
2	1.0216
3	1.0211
4	1.0214
5	1.0214
Average	1.0214

Table 4.4: Dynamic viscosities of the lubricant at max. and min. average values as measured at 28.0^0C.

Temperature in ^{0}C	Viscosity (cP)
28.5	0.9805
28.5	1.0214

According to Eugene and Theodore (1996), kinematic and dynamic viscosities, are related by the equation

$$\text{cSt} = {cP}/{\rho} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 4.1$$

where cP = viscosity in centipoise

ρ = density in g/cm^3

Using the above equation, the minimum and maximum values of the dynamic viscosities of the lubricant sample becomes:

Kinematic viscosity = 0.9808/0.93 = 1.0546cSt - min

Kinematic viscosity =1.0214/0.93 = 1.098cSt – max.

4.1.5 Specific heat capacity of lubricant sample

To determine the average specific heat capacity of the lubricant, the following measurement were made and analyzed as shown below.

Mass of calorimeter = 0.058kg
Mass of calorimeter + lubricant = 138g = 0.138kg
Mass of brass (solid) =85g = 0.085kg
Mass of lubricant =80g = 0.08kg
Initial temperature of lubricant =29^{o}C
Final temperature of brass(solid) =140^{o}C
Temperature of solid before mixture = 44^{o}C
Let the specific heat capacity of the solid be c_s
Let the specific heat capacity of the calorimeter be c_c
Let the specific heat capacity of the lubricant be c_l
N.B. c_s; 380j/kgk
c_c ; 400j/kgk.

Final temperature of mixture = Final temperature of lubricant = initial temperature of solid (see table 4.4)
Heat lost by brass (solid) = $m_s c_s \theta$
Heat gained by lubricant = $m_l c_l \theta$
Heat gained by calorimeter = $m_c c_c \theta$

Assuming no heat is lost/gained to the surroundings heat gained = heat lost.
Total heat gained = $m_l c_l \theta + m_c c_c \theta = 0.08 \times c_l \times 15 + 0.058 \times 400 \times 15$
$= (1.2c_l + 348)$j/kg k
Total heat lost = $m_s c_s \theta = 0.085 \times 380 \times 96 = 3100.8$j/kg k
Heat lost = Heat gain
$3100.8 = 1.2c_l + 348$
$3100.8 - 348 = 1.2c_l$
$c_l = 2,752.8/1.2 = 2.294$j/kg k

Table 4.5: Initial and final readings of lubricant sample and solid mixture.

Sample	Lubricant initial temp. °C	Mixture Final temp. °C	Solid final temp. °C	Specific heat capacity(J/KgK)
1	29	44.5	140	2.207
2	29	44	140	2.294
3	29	44	140	2.294
4	29	43.5	140	2.397
5	29	44	140	2.294
Average	**29**	**44**	**140**	**2.297**

4.1.6 Specific gravity

To determine the average specific gravity of the lubricant sample, the following analysis was made as shown below.

Specific gravity = density of substance/density of water.

$$= \frac{930}{990.5} = 0.939.$$

4.1.7 pH value

In order to arrive at a satisfactory value of the pH of the sample lubricant, about five different readings were taken and presented in Table 4.6.

Table 4.6: pH values of the lubricant samples.

Sample	pH value
1	7.07
2	7.03
3	7.03
4	8.03
5	7.37
Average	**7.31**

The average pH Value was **7.31** at 29°C .

4.1.8 Flash point

The experiment of the flash point of the lubricant sample was conducted about five times and values presented in Table 4.7.

Table 4.7: Flash point values of the lubricant samples.

Lubricant sample	Flash point value
1	169
2	158
3	169
4	180
5	180
Average	**171.2**

The average flash point of the lubricant sample was 171.2 ^{o}C.

4.1.9 Extrusion Tests.

Below are the results of various tests conducted under different weights percentage of the lubricant samples. The lubricant samples used in carrying out these tests are defined in Table 4.8.

Table 4.8: Description of lubricant samples.

Lubricant	Graphite (w/w %)	Castor oil (w/w %)
Sample A	10	90
Sample B	15	85
Sample C	20	80
Sample D	25	75
Sample E	30	70

The average extrusion pressures of the different samples of the formulated (castor oil-graphite) lubricant, standard lubricant and the extrusion process conducted without lubrication are presented in Tables 4.9 to 4.16. The specimens were heated at 160^{o}C in an oven for 1 hour only. The temperature was chosen based on the investigation in Figure 4.1. The ambient temperature was then 35.6^{o}C. The onset pressures (breakthrough pressures) and final pressures were obtained as shown below.

Note, the test specimens were of the following dimensions:

Length – 30mm

Billet diameter – 14mm

Extrusion diameter – 12.5mm

Table 4.9: Onset and final pressures of sample A given in Mpa

Lubricant sample A	Onset pressure (Mpa)	Final pressure (Mpa)
1	15.720	13.652
2	15.927	13.858
3	16.134	14.065
4	15.720	13.238
5	16.134	14.065
Average	15.927	13.776

Table 4.10: Onset and final extrusion pressures of sample B given in Mpa.

Lubricant sample B	Onset pressure (Mpa)	Final pressure (Mpa)
1	14.065	11.997
2	13.234	12.411
3	14.065	12.411
4	13.234	11.997
5	13.652	13.238
Average	13.652	12.411

Table 4.11: Onset and final extrusion pressures of sample C given in Mpa.

Lubricant sample C	Onset pressure (Mpa)	Final pressure (Mpa)
1	14.065	13.238
2	14.065	12.824
3	14.065	13.238
4	14.479	13.238
5	13.652	13.652
Average	14.065	13.238

Table 4.12: Onset and Final extrusion pressures of sample D given in Mpa

Lubricant sample D	Onset pressure (Mpa)	Final pressure (Mpa)
1	17.788	16.134
2	17.788	16.134
3	17.582	16.341
4	17.375	16.547
5	17.375	15.720
Average	17.582	16.175

Table 4.13: Onset and Final extrusion pressures of sample E given in Mpa.

Lubricant sample E	Onset pressure (Mpa)	Final pressure (Mpa)
1	19.443	16.961
2	19.857	17.168
3	19.443	16.961
4	20.271	17.375
5	20.271	17.375
Average	19.857	17.168

Five different extrusion pressure values were taken for each sample of the formulated lubricant and the average pressures were determined as presented in Table 4.14.

Table 4.14: Average extrusion pressures of all samples used.

Lubricant	Onset extrusion Pressure (Mpa)	Final extrusion pressure (Mpa)
Sample A	15.927	13.755
Sample B	13.652	12.411
Sample C	12.411	13.234
Sample D	17.582	16.175
Sample E	19.857	17.168

Table 4.15: Onset and Final pressures for extrusions conducted without lubricant.

Extrusion without lubricant	Onset pressure (Mpa)	Final pressure (Mpa)
1	21.718	18.616
2	21.512	19.030
3	21.925	18.616
4	21.925	18.616
5	21.512	18.202
Average	21.718	18.616

Table 4.16: Onset and Final pressures of extrusion with standard lubricant.

Standard lubricant	Onset pressure (Mpa)	Final pressure (Mpa)
1	15.720	13.652
2	16.134	13.652
3	15.306	13.238
4	15.720	12.824
5	15.720	12.824
Average	15.720	13.238

For the purpose of comparing the extrusion pressure, the Aluminium alloy specimens were extruded with:

1. without lubricant
2. with standard lubricant
3. lubricant sample B

The result of the above conditions were presented in Figure 4.3

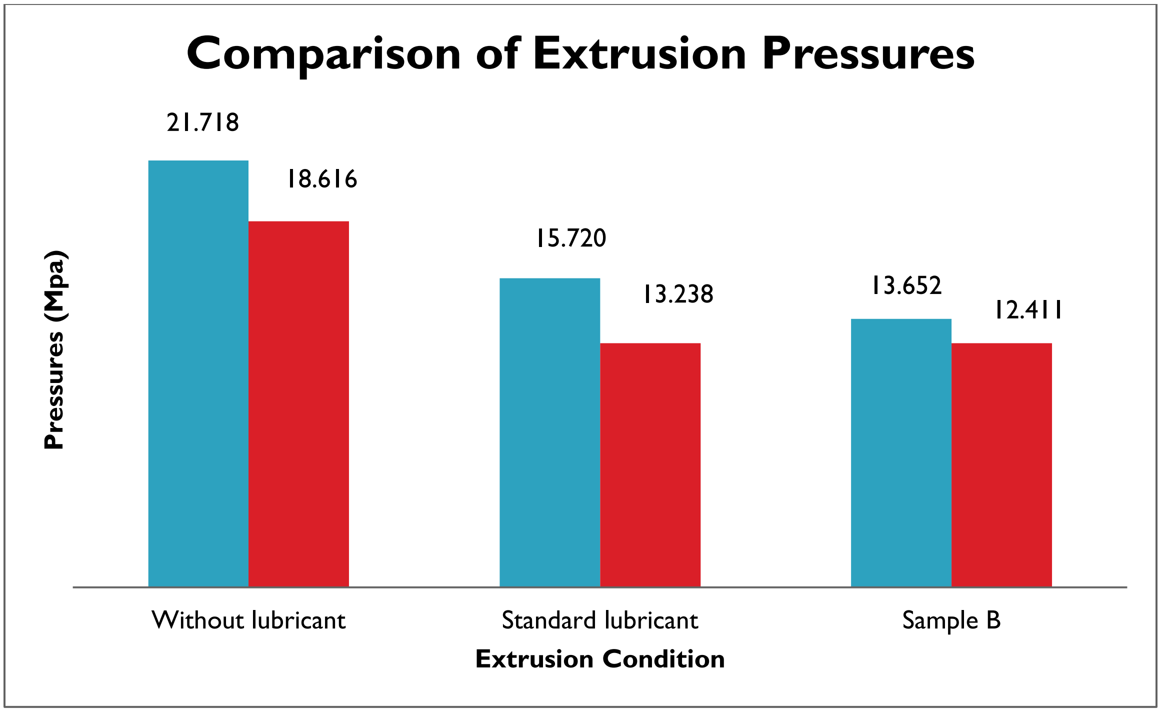

Figure 4.3: Three different conditions under which extrusion tests' results were compared at 160 ^{o}C with a holding time of one hour.

4.1.9 Hardness and Tensile properties

The results of the hardness and tensile properties of four different samples were determined and presented in Figure 4.4. The samples are defined as follows:

Specimen A & D; Unextruded Aluminium alloy

Specimen B & C; Extruded Aluminium alloy

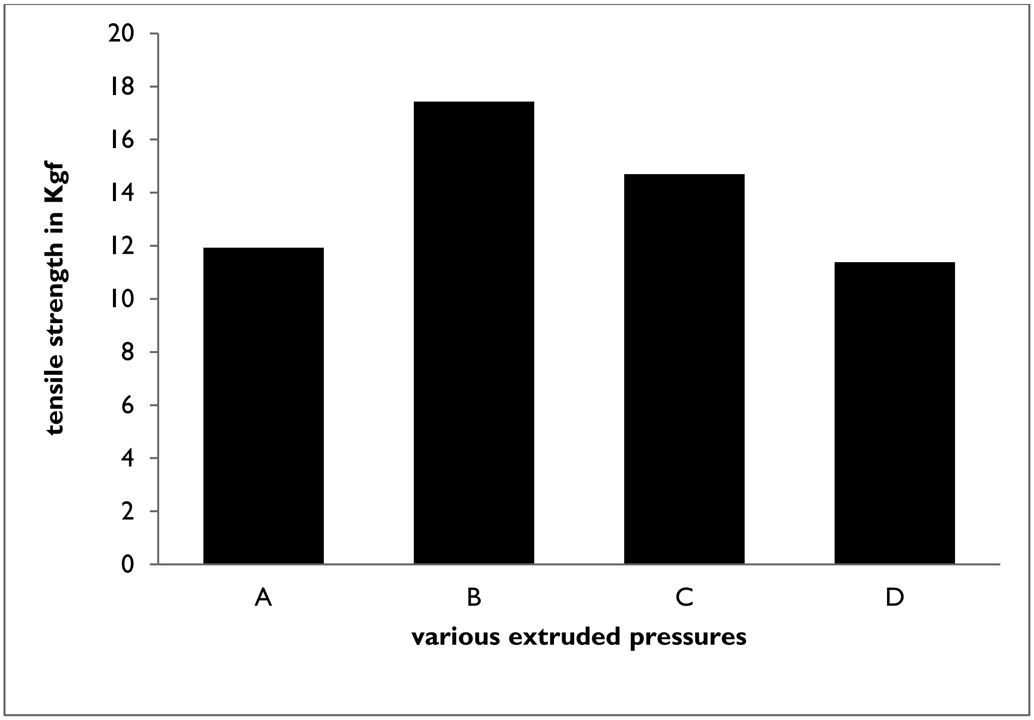

Figure 4.4: Tensile Properties of Aluminium alloy at various extrusion conditions

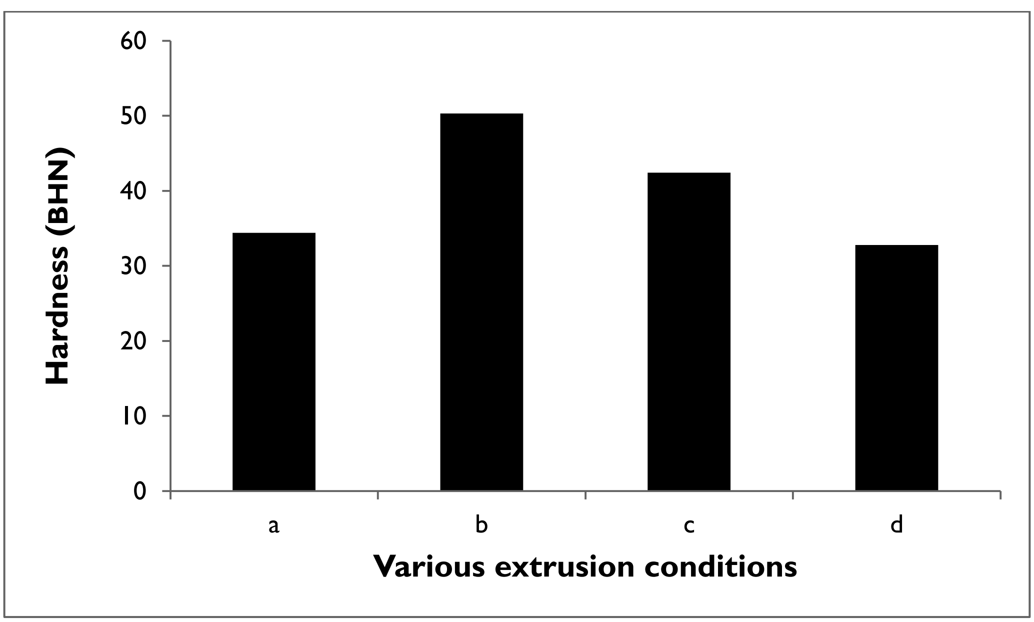

Figure 4.5: Hardness Properties of Aluminium alloy under different extrusion condition

During the experiments, certain details were captured and presented on plates. These are shown below:

Plate 4.1: Aluminium alloy extruded with lubricant.

Plate 4.2: Aluminium alloy specimens extruded at 160 ^{o}C temperature without a lubricant


Plate 4.3: Extruded Aluminium specimens showing defects.


Plate 4.4: Aluminum alloy specimen being heated in an oven.

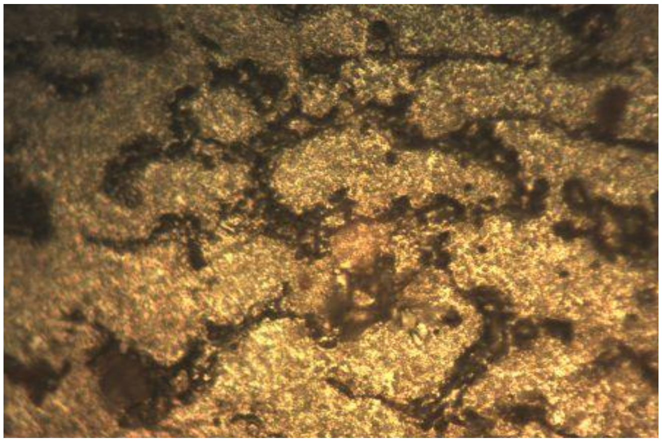
Plate 4.5: Post extrusion Aluminum specimen (magnification *400)

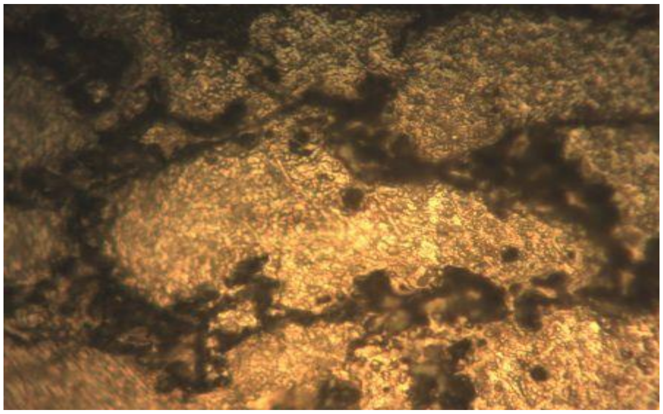

Plate 4.6: A microstructure of particle arrangement for post extrusion Aluminium specimen (magnification *800)

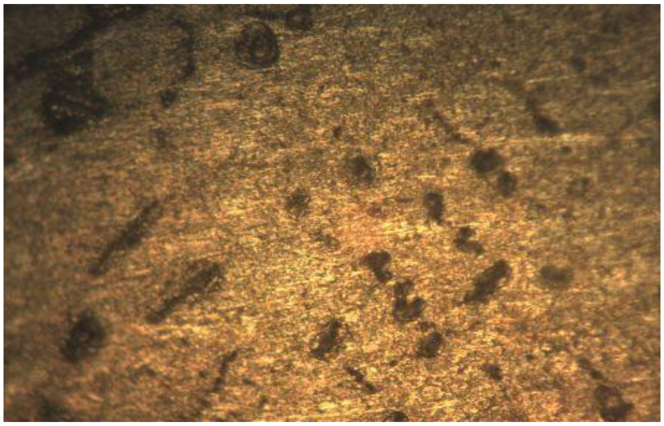

Plate 4.7: A microstructure of particle arrangement for post extrusion Aluminium specimen (magnification *400)

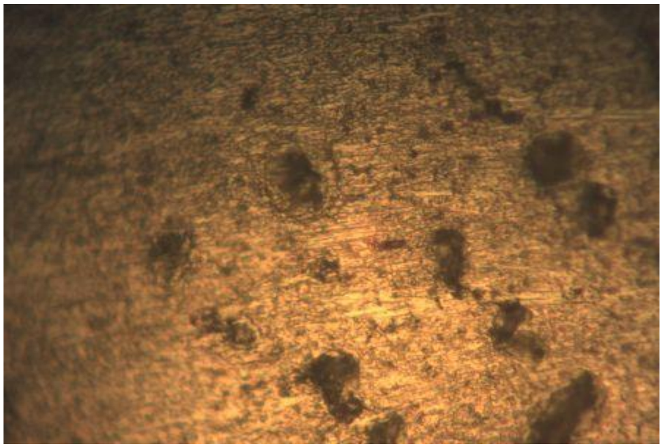

Plate 4.8: Post extrusion Aluminium specimen (magnification *800)

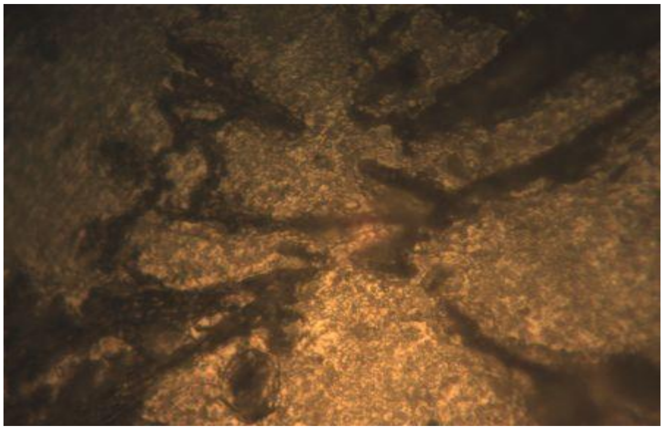

Plate 4.9: A microstructure of particle arrangement after extrusion specimen (magnification *800)

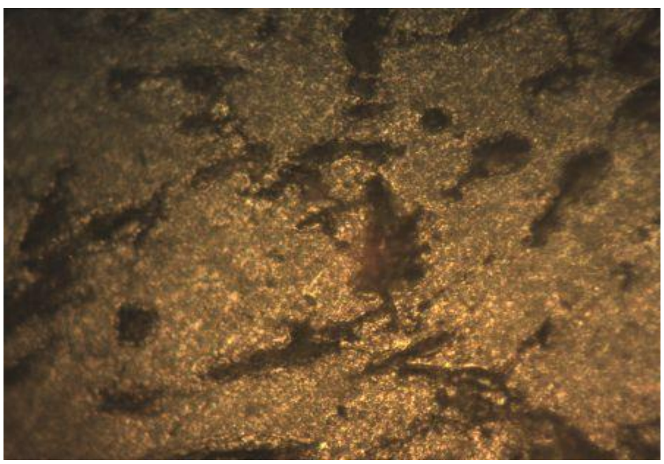

Plate 4.10: A microstructure of particle arrangement for post extrusion aluminium alloy specimen (magnification *400)

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4.2 DISCUSSION

4.2.1 Tribological properties.

i. pH value

The pH value was determined and the result is shown in Table 4.6. The pH value of the formulated lubricant samples show 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 since alkalinity are sometimes introduced for special properties and neutralization of fuel combustion products that are acidic. (Cameron and mcfethes,1987). It is expected that this singular tribological property would make it acceptable as lubricant.

ii. Flash point.

The average flash point of the lubricant was 171.2^0 C as obtained. The standard range of flash point for lubricating oils is between 40^0C and 360^0C. (www.bestsynthetic.com/techprops.shtml, 2011). The value obtained clearly indicated that the formulated lubricant can serve the intended purpose and confirmed it acceptability as lubricant.

iii. Specific heat capacity

The thermal capacity of oil 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 was 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).

iv. Density

The density of the lubricant at different temperatures were determined and presented in Figure 4.2. The densities obtained ranges from 923.5 to 930kg/m^3. This clearly shows the influence of temperature on the density of lubricants. Figure 4.2 shows that the density decreases as the temperature increases. When compared with the standard range of values for lubricating oils (between 700.0 and 980.0 kg/m^3) (Halling, 1987 and Herguth, 2000), the densities of the lubricant sample indicates its acceptability as lubricant.

v. Specific gravity

The average specific gravity of the lubricant sample was obtained as 939. The standard range of specific gravity for lubricating oils is 0.7000 to 0.9800 (Halling, 1987). Dorfman (2000) presented specific gravities (at 15.5^0 C) of cotton, red palm, cotton seed and groundnut oils as 0.9246-0.9280, 0.924-0.9279, and 0.917-0.9205 respectively. Like density, it reduces with increasing temperature. From the result (see Table 4.9), the specific density is within acceptable range.

vi. Viscosity

Kinematic viscosity is measured in centistokes. The kinematic viscosity of the lubricant sample was calculated by simply dividing dynamic viscosity by density in g/cm^3. The standard kinematic viscosity for lubricating oils is between 2 and 300 centistokes (Halling, 1987). Viscosity decreases with increasing temperature. This is equally the case with petroleum based lubricants. From the result for viscosities of the lubricant sample (see Tables 4.1 & 4.2), the lubricant sample can be used as lubricant even though is slightly below the minimum range. This is not unconnected with the presence of graphite additive. The experimental results for the extrusion of aluminium alloy (see Tables 4.9 & 4.10) show its acceptability as lubricant.

4.2.2 Extrusion pressure

During the extrusion process, the pressure was not uniform throughout the ram travel stroke. When the hydraulic ram start moving, the pressure on the billet increased rapidly to a maximum value 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. The maximum pressure recorded before the commencement of deformation is referred to as “Breakthrough pressure” or “Onset pressure”.

As the billet was being extruded through the die, the pressure required to maintain flow progressively decreases with decreasing length of the billet in the container. The pressure needed to continue extrusion reduces during the process. Therefore the minimum extrusion pressure recorded during deformation is referred to as “final pressure”. This is because the pressure 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 are usually left unextruded and discarded as a butt (Wick et al., 1984). The extrusion was stopped when almost 80 percent of the billet has been extruded. The remaining portion was not extruded but discarded. Those products which were 100 percent processed have some defects (see Plates 4.3 & 4.4). The important value of extrusion pressure here, for practical purposes is the maximum pressure occurring at the start of the process. Therefore discarding the butt was important in avoiding defects in extruded products as shown on plate 4.4. The billets temperature were raised to 160^{o}C because it was below the recrystallization temperature of the aluminium alloy specimens used which was obtained as 634 ^{o}C using an electric oven (see Plate 4.1)

The various extrusion pressures at onset (breakthrough) and final stages of the extrusion process using the formulated lubricant samples (samples A–E) measured in Mpa were obtained and presented (see Tables 4.9 to 4.13). Five different values of pressure were obtained and all indicated significant influence of lubrication on the extrusion pressure during cold extrusion of aluminium alloy specimens leading to drastic reduction in pressure. The average extrusion pressures of all samples (samples A-E) are presented in Table 4.14. The Onset and final pressures of the tests carried out without lubricant were presented in Table 4.15. Likewise the ones conducted with the standard lubricant were presented in Table 4.16. Lesser energy spent for the process when lubricant was applied.

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 21.718 Mpa was obtained. The lubricated extrusion with the formulated lubricant produced a maximum pressure of 13.652 Mpa while standard lubricant produced a maximum pressure of 15.720 Mpa.

The extrusion pressure decreases as the amount of graphite powder in castor oil is decreased from 30 to 10 percentage by weight. There was slight increase in pressure at 10% by weight of graphite. This shows that the optimum pressure value was achieved while using 15% by weight of graphite powder which was obtained as 13.652 Mpa. The petroleum based lubricant (referred to as standard lubricant) was equally tested on the aluminium specimens (see Table 4.16). The extrusion test was conducted with the petroleum based lubricant and the extrusion pressure value obtained was higher than the one obtained while using the formulated lubricant sample B. This is a confirmation of the efficacy of the formulated lubricant and was better in performance as compared with the petroleum based lubricant. These important observations were presented in Figure 4.4.

It is important to note that at 160 ^{o}C temperature level and with lubricant in use, the extrusion pressure is less and has better surface finish (see plate 4.2). This is not unconnected with the aluminium specimen's hardenability as a result of cold working process. The existence of fatty acids in the castor oil has helped the lubricant to stick well to the die's surface. It has further created a boundary lubrication condition thereby producing a product of low surface roughness.

4.2.3 Microscopic examinations

In order to identify whether extrusion process would have effect on the micro structural arrangement of the Aluminium alloy**,** image analysis was conducted on both pre and post extruded specimens using accouscope microscope fitted with a camera. Three images were taken and revealed re-arrangement of the grain structure in each plate. This is not unconnected with the flow of metal in direct extrusion which produces a deformation that increases the amount of working from front to rear of the length, and from centre of the cross section (Wick et al., 1984). In other words, Metal flow also causes a directionality of properties in extrusions.

The grain sizes of the resulting extrusion product at a magnification of ×400 (plate 4.5) and magnification of ×800 (plate 4.6) showed an elongation of the grain structure in the direction of the extrusion process. This dislocation density increases with increasing cold forming (Huda, 2009).

Plate 4.7 shows a microstructure of post extrusion specimen of aluminium alloy at a magnification of ×400 and plate 4.8 shows magnification by ×800 of the same specimen.They indicated reduction in the porosity thereby increasing the dislocation density. By comparing the microstructure with that of the unextruded specimens in plates 4.9 and 4.10 at a magnification of ×400 and ×800 respectively, new dislocations were created by cold forming.

4.2.4 Tensile and hardness properties

Cold extrusion has altered the structure of the material thereby altering the tensile properties of the resulting product. During the deformation process, strain hardening occurs at the forming zone thereby increasing both the tensile strength and hardness of the material. As expected, the tensile strength and hardness value have increased significantly (see Figures 4.3 & 4.4). The magnitude of the increase in both the tensile and hardness were not much due to small extrusion ratio that was used.

4.2.5 Product quality

Some qualities of the resulting products such as surface finish, dimensional accuracy, product curvature and defects were noted. All the aluminium alloy specimens were subjected to the same temperature of 160^{o}C (see plate 4.1).

Plate 4.2 shows typical photograph of an extrusion product with a lubricant. The final dimension of the resulting product has a fairly good dimensional accuracy and fine surface finish. Plate 4.3 shows aluminium alloy specimens extruded at 160 ^{o}C temperature level without lubricant. The increase in temperature of the aluminium alloy specimens has led to an increase in ductility with consequential reduction in power requirement. The resulting products have their surfaces cracked as a result of high temperature being developed during the process. Surface cracking is avoided by the use of suitable lubricant in order to reduce friction during the deformation process. Similarly Plate 4.4 shows resulting product of the extrusion process having some defects. The presence of impurity was not ruled out since the specimens used were cast from recycled materials. This was partly responsible for the defects observed.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 SUMMARY

In this work castor oil-graphite lubricant was formulated and its tribological and thermal properties such as pH value, flash point, specific gravity, specific heat capacity and viscosity were tested. All values obtained were found to be within the standard range of ASTM standard test methods. The findings made on each tribological and thermal properties showed that it can be used as lubricant.

There was significant influence of lubricant on the extrusion pressure observed during the process. A better performance was recorded when 15% by weight of graphite was used; this produced the lowest pressure. When compared with the standard lubricant, it showed a superior performance as well. After the extrusion process, there was an improvement in the mechanical properties of the samples. A simplified analysis of lubrication conditions arising at the start of lubricated forward extrusion is presented, which indicates that extrusion proceeds in a series of well defined stages, each characterized by that ram movement necessary to extrude one die volume of a material.

Vegetable oils are among environmentally acceptable and renewable lubricants for some interacting surfaces. The tribological properties were determined and presented. These would be used by mechanical engineers for product design and lubrication engineers for lubricant design purposes.

5.2 CONCLUSIONS

Based on the findings of this study, the following conclusions were drawn, viz:

1. The formulated castor oil – graphite lubricant that produced the lowest extrusion pressure has 15 : 85% graphite – castor oil ratio.
2. Each lubricant samples were tested five (5) times on each aluminium alloy specimens at a constant extrusion ratio. The aluminium alloy specimens were of the following dimensions: length; 30mm, billet diameter; 14mm and extrusion diameter; 12.5mm.
3. The tribological properties of the lubricant were determined and the following values were obtained: pH value: 7.31, flash point: 171.2^{o}C, density: 0.93g/cm^3, viscosity: 1.0546cSt, specific gravity: 0.939 and specific heat capacity: 2.294j/kgk. In all the cases, there was significant influence of lubricant on the extrusion pressure of aluminium alloy.

5.3 RECOMMENDATIONS

1) There is the need for measurement at varying pressure, certain lubricant properties need to be determined with tribo–meter, some thermodynamic properties also need to be measured.
2) For comprehensive frictional characterization, oils have to be tested and compared in all the regimes of lubrication.
3) Performance tests to evaluate particular aspect of in-service behavior such as anti-wear and extreme pressure properties need to be carried out. Many of the tests used are small size or bench tests for practical reasons.
4) Full scale standardized performance tests are required.
5) There is the need to generate data on input costs of vegetable oils used in lubrication across the country.
6) There is the need to carry out bench test with stretchers to remove major contour deviations.
7) Non edible oils should be exploited as far as possible so that edible oils can be freed for human consumption.

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Appendix 1

DESIGN OF THE EXTRUSION RIG

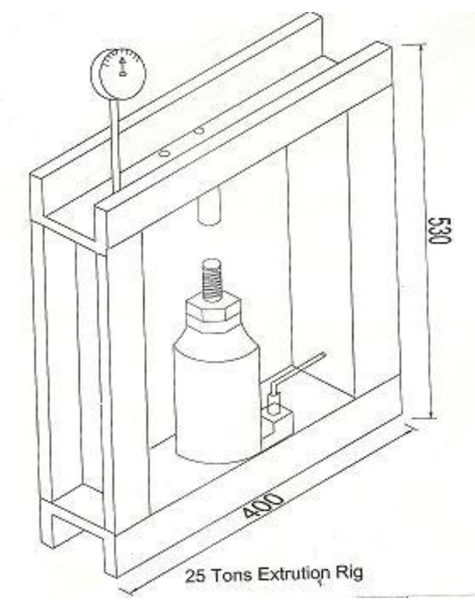
1.0 INTRODUCTION.

A manually operated hydraulic rig (vertical) has been designed and constructed for used to carry out the experiment to evaluate the effect of pressure on lubricant. Most of the investigations involving extrusion were research works conducted outside Nigeria and are yet to be verified practically in the laboratory in this country (Ugheoke and Joshua, 2005).

Laboratory size extrusion rigs are not readily available in most universities and research centres across the country and has impacted negatively on the development of process of extrusion.

The direct extrusion process was considered and the equipment was designed in such a way that it could replicate actual extrusion manufacturing process. The designed members of the system are as follows:

1 Hydraulic jack
2 mould
3 Die
4 Frames
5 Pressure gauge
6 Ram



2.0 Design Analysis And Calculations

Crucial to the determination of the rig's components listed above is the extrusion force, which the rig is required to overcome. For this reason the various forces involved were analyzed.

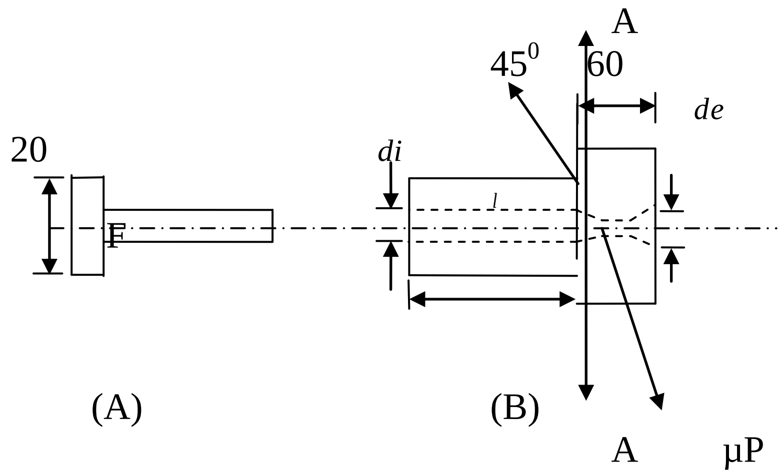


Fig:1A and 1B shows Ram and the Mould Sketch

Extrusion force is given by (Joseph and Charles, 2004),

$$F = \frac{\pi}{4} d_i^{\,2} \sigma_A + \frac{\pi}{\sqrt{3}} d_e l \sigma_y \qquad \text{..1}$$

Where

F = extrusion force

d_i= billet diameter at inlet of extrusion

d_e= final diameter of extruded product

σ_A = comperessive stress at section A-A

σ_y = tensile yield stress.

$$\frac{\sigma_A}{\sigma_y} = \frac{\phi}{\phi - 1}\left[\left(\frac{d_i}{d_e}\right)^{2(\phi-1)} - 1\right]$$

……………………………………………………2

Where φ = Tan α + μ

α = 45^0 i.e. α= Dead zone angle

$\phi = Tan 45 + \mu = 1 + \mu$

$P = \sigma_A + \sigma_Y$

Where P=Stress on included Portion of die

$\tau = \frac{\sigma_y}{\sqrt{3}}$

Where τ =shear yield stress

$\sigma_A = 4.31 Log_e\left(\frac{d_i}{d_e}\right)$

Power loss in extrusion pressure

$= \frac{\pi}{3}\sigma_y d_i^{\,2} v_A\left[l + d_i Log_e\left(\frac{d_i}{d_e}\right)\right]$

Where v_A=axial velocity at section A-A

DATA:

d_i =14mm d_e=12.5mm l = 30mm

$\sigma_y = \frac{55}{\sqrt{3}}\frac{N}{mm^2} = 31.75\frac{N}{mm^2}$

Using the equation (Ibrahim, 2008),

$$\mu = \frac{1/\sqrt{3}}{\left(1+\frac{1}{\mu}\right)\left[\left(\frac{d_i}{d_e}\right)^{2\mu} - 1\right] + 1}$$

and

And by trial and error, μ=0.317.

Substituting in

$$\boldsymbol{\sigma_A = \sigma_y \left(\frac{\phi}{\phi - 1}\right)\left[\left(\frac{d_i}{d_e}\right)^{2(\phi-1)} - 1\right]}$$

Where φ = 1+μ =1+0.317 = 1.317.

$$\sigma_A = 31.75\left(\frac{1.317}{1.317-1}\right)\left[\left(\frac{14}{12.5}\right)^{2(1.317-1)} - 1\right]$$

=31.75(4.155)(0.075)

$$\sigma_A = 9.827\frac{N}{mm^2}$$ substituting into equation (1) above,

$$F = \frac{3.142}{4}(14)^2(9.827) + \frac{3.142}{\sqrt{3}}(12.5)(30)(31.75)$$
$$= 1,514 + 21,599$$
$$= 23,113N$$
$$power = \frac{F \times d}{t} = FV_A$$

Friction Power loss in extrusion is given by

$$= \frac{\pi}{\sqrt{3}}\sigma_y d_i \left[l + d_i \log_e \left(\frac{d_i}{d_e} \right) \right] V_A$$

$$= \frac{\pi}{\sqrt{3}} \times 31.75 \times 14 \left[30 + 14 \log_e \left(\frac{14}{12.5} \right) \right] V_A$$

$$= \frac{1,396.62}{1.73} [30 + 1.59] V_A$$

$$= 807.29 [31.59] V_A$$

$$= 25,502.29 V_A$$

N.B. v_A =axial velocity at section A-A.

=25502.29 $= \frac{25502.29V_A}{23113V_A} \times 100$

$= 91\%.$

Total % loss = 91%. This is an indication of a tight fit within the billet chamber.

Total force is given below
F_T= 44,239.91N

Hydraulic jack capacity required to overcome this force is

$$F = mg, g = gravity$$

$$m = \frac{F}{g}$$

$$\therefore m = \frac{44,239.91}{10} = 4,423.99 Kg.$$

$$p = \sigma_A + \sigma_Y$$

where

P=stress on included portion of die

P = 31.75 + 9.827 = 41.58N/mm^2

Container wall thickness.

This was treated as thick cylinder lame equation was used for its design. The lame equation (Eugene and Theodore,1996)

$$\sigma = \sigma_1 \frac{r_2^{\ 2} + r_1^{\ 2}}{r_2^{\ 2} - r_1^{\ 2}}$$

Where σ=working stress=509/$\sqrt{3}$ Mpa,

σ_1= working pressure = 41.58N/mm^2

r_1 = 1nternal radius of container =14mm

r_2 = ?

$$r_2^{\ 2} = \frac{41.58(14^2) + 293(14^2)}{293 - 41.58} = 335.84$$

$$r_2 = \sqrt{335.84}$$

$$\therefore r_2 = 18.33mm.$$

$$r_2 - r_1 = 18.33 - 14.00 = 4.33mm.$$

5mm was adopted for thickness.

Die thickness.

Die thickness was obtained from the plate formula, (Theodore and Eugene,1996).

$$t = \sqrt{\frac{K\sigma_e D_D^{\ 2}}{4[\sigma_{all}]}}$$

Where K = 1.24 .

σ_e =extrusion stress

σ_{all} = allowable stress

D_D = diameter of die

$$t = \sqrt{\frac{1.24(41.58)(12.5^2)}{4(293)}}$$

$$t = 6.87mm$$

7mm was adopted

Ram Diameter (d_r)

This was considered as a compression block and design criterion used is

$$\frac{p_o}{A_o} \le \sigma_{all}$$

Where p_o = extrusion force

A_o = cross sectional area of ram

σ_{all} = allowable stress of steel 1030 = 293.87MPa

$A_o = \frac{\pi d_r^2}{4}$, where d_r = ram diameter.

$$\frac{44239.91 \times 4}{\pi \times d_r^2} \le 293.871$$

$$\frac{176959.64}{\pi \times 293.871} \le d_r^2$$

$$\therefore 13.84 \le d_r.$$

The case is sliding fit of class corresponding to tolerance grade H7 and g9. i.e.

Hole = (14.018 – 14.000)
Shaft = (13.994 – 13.984)

Max. clearance = 14.018mm
Min. clearance = 0.006mm

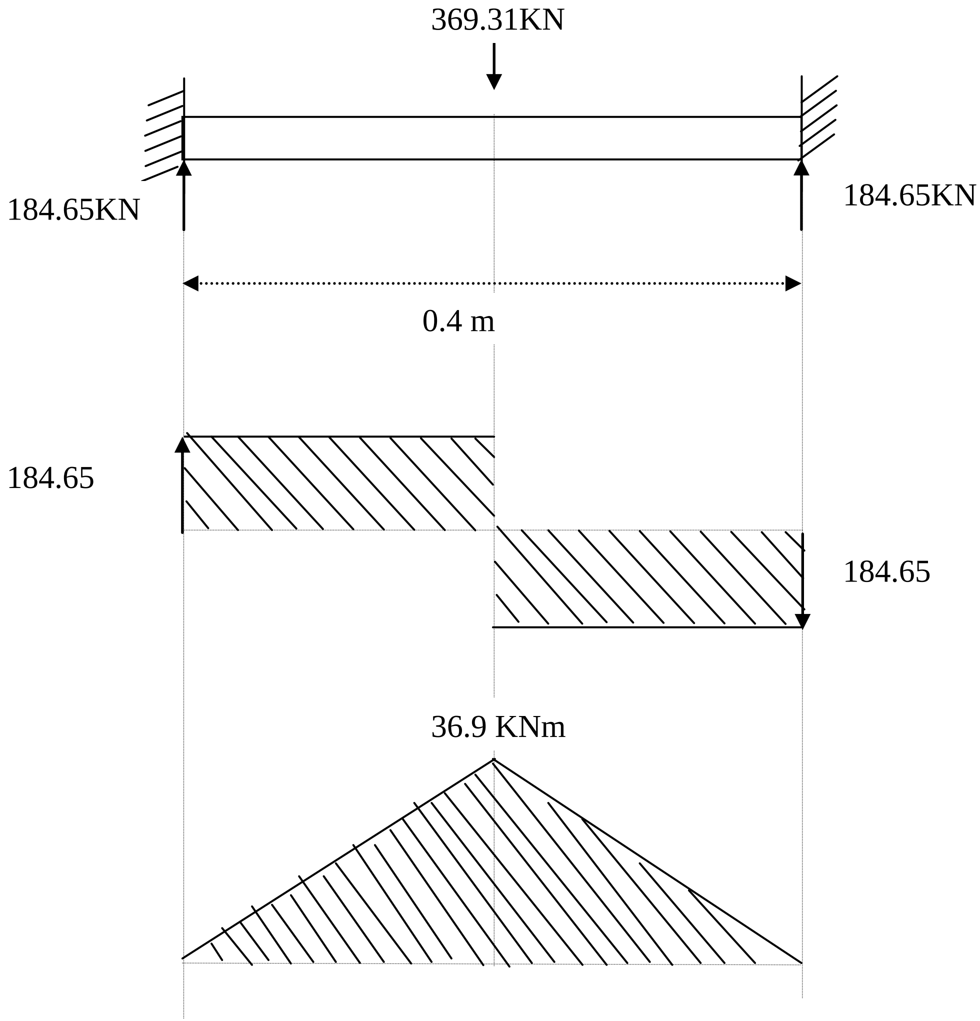
3.0 BEAMS AND COLUMNS

3.1 Beams

The design criteria used for this member was the ability of the chosen section to be able to resist deflection. They are pinned at both ends. Structural steel as a beam thus considered as follows:

Maximum pressure applied during loading = 3150 psi or 21724kN/m^2
Cross sectional area of the hydraulic jack =0.017m^2.
Force applied = 21724 × 0.017 =369.31KN.

Bending moment diagram



Structural steel channel 102 × 51 with I = 236.8cm^4 was selected.

From table E-11, (Shirgley, 2004) pg1169,

$$I = I_{1-1} + I_{2-2}$$
$$I = 207.7 + 29.10 = 236.8cm^4$$

$$p_{cr} = \frac{\pi^2 E\mathrm{I}}{l/2} = \frac{3.142^2 \times 207 \times 10^9 \times 237 \times 10^{-8} \times 2}{0.530}$$
$$p_{cr} = 1.82 \times 10^7 N = 1.82 \times 10^4 KN$$

Since maximum load applied is 369.31KN, and critical load of the structural steel channel is p_{cr}=1.82$\times 10^{7}$KN, the assembly will be safe.

Appendix 2

pH values of some selected substance.

SUBSTANCES	pH	
Hydrochloric Acid (HCl)	0.0	ACID
Gastric Juices	1.0	
Lemon Juice	2.3	
Vinegar	2.9	
Wine	3.5	
Tomato Juice	4.1	
Coffee (black)	5.0	
Acid Rain	5.6	
Urine	6.0	
Rainwater	6.5	NEUTRAL
Milk	6.6	
Pure Water	7.0	
Blood	7.4	
Baking Soda Solution	8.4	
Borax Solution	9.2	
Toothpaste	9.9	
Milk of Magnesia	10.5	
Limewater	11.0	ALKALINE
Household Ammonia	11.9	
Sodium Hydroxide (NaOH)	14.0	

Appendix 3