EVALUATION OF NEEM (*AZADIRACHTA INDICA*), TIGER NUT (*CYPERUS ESCULENTUS*) AND FALSE WALNUT (*CANARIUM SCHWEINFURTHII*) OILS AS METAL WORKING LUBRICANTS

By

GAMINANA, JIMOH OHINOYI

B. Eng (Met.) (A. B. U.)

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In partial fulfillment of the requirements for the award of Master's degree in Metallurgical and Materials Engineering.

Department of Metallurgical and Materials Engineering, Faculty of Engineering

Ahmadu Bello University, Zaria, Nigeria

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DECLARATION

I hereby declare that the work in this thesis titled "Evaluation of Neem (*Azadirachta indica*), Tiger nut (*Cyperus esculentus*) and False walnut (*Canarium schweinfurthii*) oils as Metal Working Lubricants" was performed by me in the Department of Metallurgical and Materials Engineering, A. B. U., Zaria, under the supervision of Prof. A. K. Oyinlola and Dr. G. B. Nyior.

The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this work has been presented for another degree or diploma at any institution.

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GAMINANA, Jimoh Ohinoyi Date

CERTIFICATION

This project thesis titled “Evaluation of Neem (*Azadirachta indica*), Tiger nut (*Cyperus esculentus*) and False walnut (*Canarium schweinfurthii*) oils as Metal Working Lubricants” meets the regulations governing the award of the degree of Master’s of Science (Metallurgical and Materials Engineering) of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

………………………… ……………………….

Chairman, Supervisory Committee Date

Prof. A. K. Oyinlola

………………………… ……………………….

Member, Supervisory Committee Date

Dr. G. B. Nyior

…………………… ……………………

Head of Department Date

Dr. Ola Aponbiede

……………………. …………………….

Dean, School of Postgraduate Studies Date

Prof. A. A. Joshua

DEDICATION

To my parents, my wife and kid.

ACKNOWLEDGEMENTS

All praise and thanks be to God. I wish to express my profound gratitude to my supervisors Prof. A. K. Oyinlola and Dr. G. B. Nyior for their endless support in the entire course of this project work. They were never tired of listening and proffering solutions to my problems. My gratitude also goes to the Dr. S. A. Yaro for his moral support especially at difficult times. I am indeed grateful.

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ABSTRACT

Performance evaluation of neem, tiger nut and false walnut oils with respect to their effectiveness in friction reduction in cold mild steel drawing and cold aluminum rolling operations have been carried out in this research work. While a 500 kN Denison machine was improvised for use in lieu of a laboratory draw bench for the wire drawing operation, the plane-strain compression test was used to simulate rolling operation. Sodium stearate in methyl alcohol was used as a standard of performance assessment in wire drawing while paraffin (kerosene) was used in the plane-strain compression test. From the results obtained, false walnut oil gave the best performance in both the drawing and rolling operations with an average coefficient of friction value of 0.12978 in the drawing test and a percentage reduction of 52.19 in the plane-strain compression test. The results of this work also revealed that false walnut oil performed better than the standards used for assessment in both tests. The obtained coefficient of friction for drawing using neem oil, tiger nut oil and sodium stearate respectively were, 0.23042, 0.19622 and 0.16108 while the percentage reductions in plane-strain compression test for neem oil, tiger nut oil and paraffin were 47.0%, 51.5% and 41.1% respectively.

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μ	coefficient of friction
σ_x	longitudinal stress
σ_o	flow stress
σ_o	mean flow stress
σ_{xa}	axial stress at the die exit (draw stress)
σ_{xb}	back pull stress
σ_{xf}	front flow stress
σ_1	major principal stress
σ_2	minor principal stress
r	percentage reduction
α	half die angle, angle of bite
	strain under homogeneous deformation
*	enhanced strain
Φ	redundant work factor
τ	frictional resistance
A_b	initial drawing area
A_a	final drawing area
p	mean normal pressure
P_d	draw force
P	normal pressure, rolling load
R_o	initial radius
R_f	final radius
h_o	entrance sheet thickness
h_f	exit sheet thickness

v_o	entrance sheet velocity
v_f	exit sheet velocity
b	width of sheet
L_p	length of arc
P_r	radial roll pressure
h	mean thickness between entry and exit from rolls
	specific roll pressure

CHAPTER ONE

1.0 INTRODUCTION

Tribology is defined as the science and technology of interacting surfaces in motion and of related subject and practice (Arnell *et al.*, 1991; Halling, 1978). It has also been defined as the science and technology of friction, lubrication and wear (Szeri, 1980).

Tribological problems are not just confined to the machines we use; they have profound influences on many aspects of life. The actions of animal joints is clearly a tribological situation and cures for diseases such as arthritis already owes much to the tribological expertise (Halling, 1978).

Friction and wear which are components of tribology have been with us since time immemorial; so has been our effort to control the former and minimize the latter (Halling, 1978). Friction is the resistance to relative motion of two solid surfaces in contact and can waste power, overheat moving parts and cause wear which itself can lead to failure (McGannon, 1970). Friction and wear cause loss of millions of dollars annually in lost production, lost time, lost materials and wasted energy. Lubricants can be used more efficiently to reduce this cost (Szeri, 1980).

Lubrication, the third constituent of tribology consists of interposing a fluid film between adjacent solid surfaces that move in relation to each other. It implies the intentional use of a substance that reduces friction between contacting surfaces and is a mitigating factor in wear. Lubricants thus serve to (i) provide a coherent film between the surfaces (ii) remove heat from the contact, and (iii) prevent the ingress of dirt and other contaminant (ASM, 1978).The reduction of friction and wear by lubricants results from the formation of a film separating the rubbing surfaces. The thickness of the lubricant film depends upon its constituent chemistry (Roegiers *et al.*, 2008).

From the time when humans first built and moved objects, lubricants have been a part of every day existence. It was learnt that unctuous, greasy materials were slippery and made it easier to push and move materials (Szeri, 1980). Olive oil has been used as long as 1650 B.C. Various oils from olive, castor bean, rapeseed, palm oil and fats from sperm whale, animal lard and wool grease were used from time as early as 50 A.D. (Gawrillow, 2003).

Until the 19th century, lubricants have been manufactured mainly using (even exclusively) vegetable oils and animal fats (Stefanescu *et al.*, 2002). When the internal combustion engines appeared, these "classical" lubricants were gradually replaced by mineral oils. The main cause of this change is stability in time both for stocking and functioning (Stefanescu *et al.*, 2002).

The development of lubricant based on mineral oils as a base fluid is related to the good technical properties and the reasonable price of mineral oils (Willing, 2001).

Use of mineral oils as lubricants itself presents certain challenges, one of which is its poor biodegradability and thus its potential for long term pollution of the environment (Willing, 2001).

Another important factor as reported by Willing (2001) is the fact that petroleum resources are limited, hence the need for the development of alternative source of lubricating oils for industrial applications.

It is known from the early development of lubricant for special applications, that fatty acid polyesters have comparable or even better technical properties than mineral oils, and that the fatty acids are almost exclusively based on renewable resources (Willing, 2001). Also, the use of rapidly biodegradable lubricants could significantly reduce environmental pollution (Gerulova *et al.*, 2010). Accordingly, the research in the last 20 years for manufacturing new products being neutral concerning their influence on the environment makes the vegetable oils attractive again for lubricating purpose (Stefanescu *et al.*, 2002).

Prior to recent developments, vegetable and animal oils in tribology have functioned mainly as additives to mineral lubricating oil formulations, although in some cases they are applied exclusively, or in blends (Aluyor *et al.*, 2009).

Vegetable oils offer a wide range of advantages which includes biodegradability, renewability (Gawrillow, 2003), low toxicity (Stefanescu *et al.*, 2002), good lubricity, high viscosity and high viscosity index (Leugner, 2003).

Naturally, vegetable (consisting primarily of triglyceride molecular structure) have performance limitations such as poor thermal and oxidative stability. For instance, most vegetable oils cannot withstand reservoir temperature greater than 80^oC (Leugner, 2003). However, they have good lubricating properties due to their polar nature which provides good metal wetting attraction. This also makes them good solvent for keeping debris and dirt off metal surfaces. Their molecular structure provides for high viscosity and high viscosity index (Leugner, 2003).

Lubricants from vegetable origins have also been derived from sunflower, soya bean and coconut tree (Stefanescu *et al.*, 2002).

Previous works done on neem seed and tiger nut oils suggest their potentiality as attractive lubricants based on the fact that they are mainly fatty acid in composition (Shamagana, 2008 and Olatunji, 2006).

Tiger nut oil was reported to have high content of gamma-tocopherol which gave it a high resistance to oxidation (tigernut.com, 2008). It was also reported to have good resistance to high temperature chemical decomposition (tigernut. com, 2008). Both neem seed and groundnut oils did not only perform well in extrusion process; their blend gave a better result than the individual oil (Shamagana, 2008). The result agreed with the fact that lubricating oils (either mineral or vegetable based) could not meet most lubrication performance needs without additives (Gawrillow, 2003). Accordingly, blending has been established as a useful method for improving the performance of lubricants.

1.1 BACKGROUND OF THE RESEARCH

Almost all processes in mechanical working of metals involve deformation of the material between comparatively rigid dies. Because of the change in shape of the stock, relative movement usually occurs between the stock and the die surfaces and this movement is opposed by friction (Male, 1964-65). Forces, flow patterns, tool wear and surface finish of the product are all affected by friction (Evans and Avitzur, 1968). Friction generally raises forces and power requirement, subject the tool to higher pressure, renders deformation less uniform within the work-piece, raises interface temperature and may set limit to attainable deformation. Consequently, attention has always been given to the problem of providing low values of friction coefficient which can be achieved by proper lubrication. Since the complete analysis of any metalworking process considers the coefficient of friction as a variable, a quantitative knowledge of its values acting during processing is desired (Evans and Avitzur, 1968). Several researches have been conducted in the past to measure friction coefficient as well as to evaluate lubricants for its reduction. The plane-strain compression test developed by Watts and Ford in 1952 has become a well established method for lubricants evaluation for various processes as well as for the determination of friction coefficient in metal working operations. Male and Cockcroft (1964-65) developed the ring compression test for the evaluation of lubricants in both cold and hot working operations. The test provides a means of measuring the coefficient of friction without measuring the mechanical properties of the metals. This is obtained by measuring the internal diameter of a compressed ring. The internal diameter increases if the friction coefficient is small and decrease if it is large. A quantitative estimation of coefficient of friction during metal working operations under different lubricating conditions was established by Takahashi and Alexander (Takahashi and Alexander, 1961-62), while Evans and Avitzur (1968) developed an experimental procedure for the evaluation of coefficient of friction for processes like wire drawing and rod extrusion through open dies and for hydrostatic extrusion and for rolling. Guminski and Willis (1959-60) used the plane strain test to assess lubricants for rolling of aluminum, while Male (1966) used the ring compression test to study the variation of friction coefficient of metals with the amount of compressive deformation at room temperature. Owing to high pressure and low speeds in most metal forming operations, lubrication is of the boundary type. To provide sufficient adherence to the metal surface for effective boundary lubrication, polar lubricants such as fatty oil, fatty acids, soaps and waxes are used. The long-chain fatty acids possess to the highest degree, the physical and chemical characteristics necessary to form solid surface layers as boundary lubricants (Schey, 1970). Hence, researches on the use of vegetable oils as metal working lubricants have been well-documented. The free fatty acids of vegetable oils form metallic soap with metal surfaces during metallic lubrication under boundary lubrication conditions encountered in metal working and to a large extent, in gear transmission system (Oseni and Nuhu, 2000). Agwandas (1988) evaluated the performance of local vegetable oils (palm, groundnut, sheabutter, palm kernel, and cotton seed oils) as lubricants for cold rolling of aluminum and found out that they were suitable lubricants as they permit higher reduction more than the standardized EP 140 rolling lubricant.

Yaskuma (1989) assessed the lubricating efficiency of these oils in cold rolling of low carbon steels and observed that they all gave better coefficient of friction values better than that obtained using the commercial SAE 30 lubricant.

Oche (1992) assessed the suitability of palm, ground nut, and sheabutter oils as drawing lubricants for steel and copper wire drawing operations. The frictional values obtained under these oils lubrication conditions were at par with the frictional obtained using standard wire drawing lubricants. Nyior (1994) investigated the performance of some vegetable oils (palm, groundnut, soya bean, and sheabutter oils) as lubricants for cold extrusion of Aladja ST 60-02 structural steels and found out that they all performed better than the standard zinc phosphate/sodium stearate lubricant at higher reduction speed. At lower reduction speed, the soya bean and groundnut oils gave similar frictional values with the standard oil.

Obi and Oyinlola (1996) investigated the frictional characteristics of palm oil and sheabutter oils in wire drawing operation. They observed that palm oil performed better than the standard sodium stearate drawing lubricant. Equally the sheabutter oil’s performance was at par with the standard wire drawing lubricant.

It was also established that in addition to the large amount of lubricating agents such as palmitic and oleic acids present, the physicochemical properties of these oils (especially iodine and fatty acid values) also enhanced their performance. Coconut oil, though a good boundary lubricant as far as coefficient of friction is concerned, cannot be used unmodified as a two-stroke engine oil.

The anti-wear and extreme pressure tribological properties could be improved by adding suitable AW/EP additives (Jayadas *et al*., 2006).

Oseni and Nuhu (2006) investigated the rheological behaviour of wild melon oil lubricant blended with transmission oil. They observed that the blending reduced the viscosity drop with temperature. In addition, the shear stress of the blend increases thereby promoting the blended oil to be used in various transmission systems.

Shamagana (2008) investigated the suitability of using the blend of neem seed and groundnut oils as lubricant for cold extrusion of mild steel. He observed that the blend gave better performance than each of the individual oil due to the additive nature of the properties of these oils.

Based on the existing knowledge, not much has been reported on the practical performance of tiger nut and false walnut oils as lubricants, even though the high content of gamma-tocopherol of tiger nut oil means it has a high resistance to oxidation (tigernuts.com, 2008).

Friction, lubrication and wear -the entire spectrum of tribology- have not been totally addressed in this investigation. Non availability of wear measuring equipment did hamper the evaluation of wear resistance of each oil under investigation. Accordingly, friction and lubrication potentials of neem seed, tiger nut and false walnut oils as metal working lubricants have been evaluated.

1.2 AIMS AND OBJECTIVES OF THE STUDY

The objectives of this research work include the following;

(1) Evaluation of the effectiveness of neem seed, tiger nut and false walnut oils as lubricants in wire drawing operations.

(2) Evaluation of the reduction capacity of neem seed, tiger nut and false walnut oils in cold rolling operation.

(3) Preliminary background research for information for further work on the enhancement of their properties as metal working lubricants.

1.3 JUSTIFICATION FOR THE RESEARCH

The need for Nigeria as a developing nation to put her vast material resources (agricultural materials inclusive) to good economic use can not be overemphasized. Much research work has been done on vegetable oils since they offer outstanding tribological properties which, among others, can be seen from their very good viscosity – temperature behaviour. Apart from this, they are better lubricants than mineral oils (Fachagentur, 2006).

The evaluation of the partial tribological properties (friction and lubrication) of neem seed, tiger nut and false walnut oils will enhance their economic value and serve as alternative to mineral oil since their expected lower evaporative loss will have less adverse effect on the environment. This could open up production income alternative in the agriculture industry.

1.4 CONTRIBUTION TO KNOWLEDGE

Many researches have been carried out on alternative lubricants using renewable and less toxic vegetable oils such as rapeseed, coconut, palm oils e.t.c.

This research work has established the effectiveness of neem seed, tiger nut and false walnut oils as good boundary lubricants; hence they are useful in the reduction of friction under boundary lubrication condition.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

The importance of tribological considerations in metal forming processes have been generally recognized as affecting tool and die life, material flow during forming, work-piece integrity and surface finish, the relationship of the lubricant to the machine elements, cost considerations and energy conservation (Kalpakjian, 1986).

Much knowledge and expertise already exist in the application of tribological principles so that an acceptable end product can be manufactured. On the other hand whether or not these applications have been optimized for each particular case or process is open to some doubt (Kalpakjian, 1986).

Finding solution to tribological problems involves analysis of the major components of tribology which are friction, wear and lubrication.

2.2 FRICTION

Friction is the resistance to motion which occurs whenever one solid body slides over another. The resistive force, which acts in a direction directly opposite to the direction of motion, is known as the frictional force (Arnell *et al.*, 1991; Halling, 1978).

2.2.1 Laws of Friction

There are two basic laws of friction, namely (Halling, 1978):

(i) Friction is proportional to the normal force between surfaces.

(ii) Friction is independent of apparent area of contact

2.2.2 Coefficient of Friction

The first law of friction provides means to define the coefficient of friction. The law states that the friction force, f is proportional to the normal load w, (Halling, 1978).

i.e. $f \propto w$ …………………… ………………………………………………………………2.1

hence, $f = \mu w$………………………………………………………………………………… 2.2

where μ is a constant known as the coefficient of friction.

It must be stressed that μ is constant only for a given pair of sliding materials and under given sets of ambient conditions (Halling, 1978).

2.3 LUBRICATION

Lubrication consists of interposing a film (either liquid, solid or gas) between adjacent solid surfaces that move in relation to each other. It implies the intentional use of a substance that reduces friction between contacting surfaces and it is simultaneously a mitigating factor in wear (ASM, 1978).

Whenever possible, a film of lubricant should be maintained which is sufficiently thick to separate the surfaces completely (Rowe, 1978). There is no advantage in exceeding this thickness (Rowe, 1978). The functions of a lubricant aside reducing friction includes; to reduce wear, carry away heat, keep dirt away from bearing surfaces, prevent rusting and transmit power (McGannon, 1970). Lubrication is usually considered under the following headings: hydrodynamic, boundary, extreme pressure and solid-film (Rowe, 1978).

2.3.1 Hydrodynamic (thick film) lubrication

This is the type of lubrication where the sliding surfaces are separated by a relatively thick lubricant film and the lubrication process is primarily a function of the material of which the lubricant is composed (Szeri, 1980). The thick films of lubricant may be established by the viscous force acting on the fluids. This is encouraged by a small angle between the tool and the work-piece, and by high relative speed.

For general applications, it is possible to increase the amount of lubricant entering the working space by trapping it in surface pockets formed either directly on the work-piece or by suitable surface treatments such as phosphating (Rowe, 1978).

2.3.2 Boundary lubrication

Boundary lubrication occurs where the sliding surfaces are separated by only a few molecular layers of the lubricant. In boundary lubrication, the bulk properties of the lubricant (such as viscosity) are of little importance, but the chemical constitution of the lubricant and that of the underlying metal assume great significance (Schey, 1970).

Some lubricants are remarkably effective as very thin films. Experiments have shown that even monomolecular layers of some compounds (known as boundary lubricants) will provide low friction, though such films are of course quickly worn away(Rowe, 1978). Liquid or solid fatty acids are particularly effective, the reason been that they react with a metal surface to form a solid metallic soap (Rowe, 1978).

2.3.3 Extreme pressure lubrication

One disadvantage of boundary lubricants is that they are usually organic compounds which decompose at temperatures of 250^oC or less. For protection at higher temperatures, chlorinated organic compounds are used. These react to form solid chlorides such as $FeCl_2$ which decomposes at about 350^oC. They were first developed for use in gears subjected to high pressure and have now become known as extreme pressure or E. P. additives. Sulphur compounds are also used. They form sulphides such as FeS which decomposes at about 700^oC (Rowe, 1978).

2.3.4 Solid-film lubrication

This involves lubrication in which a solid material is interposed between moving bodies. Any material of lower shear strength than the metal can in principle be used as a solid lubricant in metal working (Rowe, 1978).

2.4 LUBRICANTS

Lubricants are called upon to fulfill a number of functions. These include reduction of friction (which in turn lowers forces and energy requirements and permits greater deformations), dictating the surface quality of the finished product and to reduce, control, or eliminate pick up of work-piece material on the tool surface, wear of the die, and scoring of the finished product. Lubricants may also contribute to the success of the operation by preventing heat loss from a work-piece, by insulating the die from the heat of the work-piece, or by cooling the work-piece and die that would otherwise heat beyond acceptable limits because of the heat of friction and deformation (Schey, 1970).

2.4.1 Classification of Lubricants

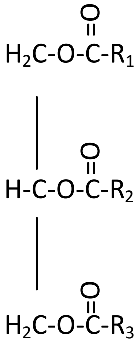
(i) Liquid Lubricants

These are lubricants that are liquids at room temperature. They provide a fluid film lubricating effect or a thin film quasi-hydrodynamic effect in machinery and give better performance than semi solids. They also help to cool moving parts and remove wear debris from the lubrication area (Szeri, 1980).

Liquid lubricants include the following;

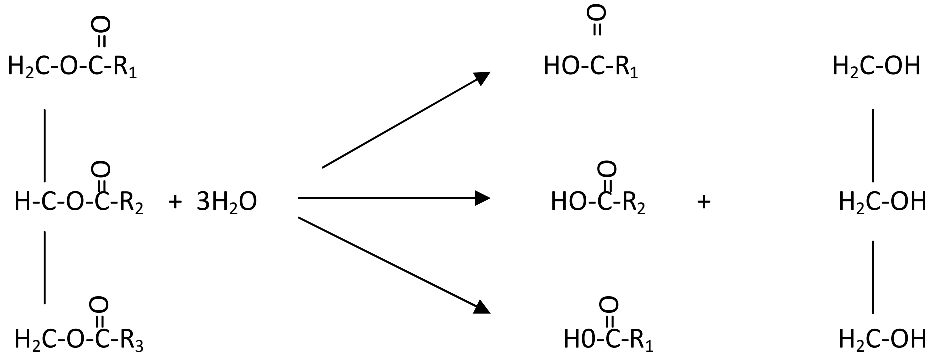
(a) Natural fatty oils

Natural oil consists of water-insoluble fats and oils derived from plant and animal sources; the major components are glyceryl esters of fatty acids (Schey, 1970). Glycerine is a tri-functional alcohol, $CH_2OHCOHCH_2OH$, and the derived fats and oils are triglycerides,



$$\begin{array}{l} H_2C-O-\overset{O}{\overset{\parallel}{C}}-R_1 \\ \quad | \\ H-C-O-\overset{O}{\overset{\parallel}{C}}-R_2 \\ \quad | \\ H_2C-O-\overset{O}{\overset{\parallel}{C}}-R_3 \end{array}$$

where the alkyl substituents R_1, R_2 and R_3 may be identical or not. The oils are described in terms of the fatty acid released when the triglyceride is hydrolyzed. For instance, if $R_1 = R_2 = R_3$ is $(-C_{17}H_{35})$ in equation 2.3, stearic acid is released in the free state.



……….………….2.3

The non-glyceride components of fats and oil constitute less than 5% of their constituents, hence their contribution to lubrication properties are minimal (Schey, 1970).

(b) Mineral oils

Their classification includes petroleum, coal, shale, tar sands, gilsonite, and peat although the only production of any significant magnitude since the late nineteen century has been from petroleum (Szeri, 1980).

(c) Synthetics

These are manufactured lubricants that do not exist in nature. They are lubricating fluids used in advanced technological conditions (especially where high oxidative and thermal stability is required) (Szeri, 1980).

(ii) Semi Solid Lubricants

These include soft solid fats and waxes that are used where circulating liquid lubricants cannot be contained and where cooling by the lubricant is not required. They include greases, soaps, fats, waxes and pastes (Szeri, 1980).

(iii) Solid Lubricants

Solid lubricants are used under conditions where boundary lubrication prevails because they provide a more stress resistant surface than do liquids. They are also used under very high temperature conditions. Solid lubricants include particulates, composites, polymers, soft metals, surface conversion coatings and glasses (Szeri, 1980). Any material of lower shear strength than the metal can, in principle, be used as a solid lubricant in metal working (Rowe, 1978).

(iv) Gases

Gases or vapours under proper circumstances can be used as lubricants. Their principal use is in air bearings (Szeri, 1980).

2.4.2 Important properties of liquid lubricants

(i) Viscosity: This is defined as the resistance of an oil to flow or shear. The ability of an oil to form and maintain a fluid film depends primarily on its viscosity. In general, heavy (high-viscosity) oils are based on parts moving at slow speeds under high pressure because it better resists being squeezed out from between rubbing surfaces (McGannon, 1970). Light (low-viscosity) oils are used when higher speeds and lower pressures are encountered, because they do not impose as much drag on the high speed parts and the high speed permits a good oil wedge to form even though the viscosity of the oil is low (McGannon, 1970).

(ii) Iodine value: The iodine value of an oil is the number of grams of iodine absorbed by 100 grams of an oil. As a molecule of iodine add across each of the double bond of an unsaturated fatty acid, the iodine value gives a measure of its degree of unsaturation (Biochemistry Dept., 2011). In general, the higher the degree of unsaturates, the greater the chemical reactivity. From the lubrication point of view, the greater the amount of unsaturated, the less the resistance to oxidation (Szeri, 1980).

(iii) Saponification value: This is the number of milligrams of potassium hydroxide required to saponify one gram of an oil. It is a measure of potential for alkali soap formation. Three molecules of hydroxide are required to hydrolyze the three fatty acid ester bonds of a triacylglycerol regardless of the size of the fatty acid residues. Thus saponification value gives a measure of the mean chain length of the fatty acids (Biochemistry Dept., 2011).

(iv) Pour point: This is the lowest temperature at which a given oil will flow or pour under prescribed conditions when it is chilled without disturbance at a fixed rate (McGannon, 1970).

(v) Flash point: This is the temperature at which a flash (momentary ignition) occurs at any point on the surface of an oil when a flame is passed over it, but the oil does not continue to burn (McGannon, 1970).

(vi) Fire point: The fire point of an oil is the temperature at which ignition occurs at any point on the surface of an oil when a flame is passed over it and the oil continues to burn. This temperature is about 10^{o}C above the flash point (McGannon, 1970).

(vii) Demulsibility: When water enters a lubricating system and is churned up with the oil, an emulsion is formed that has poor lubricating properties. If the oil is clean it will separate from the emulsion when the latter is allowed a rest period. Demulsibility is good if the oil separate quickly and bad if it separates slowly (McGannon, 1970).

2.5 METAL WORKING PRINCIPLES

The ultimate goal of a manufacturing engineer is to produce components of a selected material with a required geometrical shape and a structure optimized for the purpose of service environment. Of the above aspects, production of the desired shape is a major part of the manufacturing process (DeGarmo *et al.*, 1979).

In the mechanical deformation process, the main objective is to produce metals and alloys with a wide variety of shapes and sizes required for industry. It would be largely unnecessary to work metals if they could be cast with good mechanical properties, and in the wide variety of sizes and shapes as required by industry. A serious difficulty is that most casting requires considerable working to refine the crystal structure and homogenize the metal or alloy (Rowe, 1978). The main factors characterizing the metal working process are the degree of plastic deformation of the work piece and the intensity of relative motion between tool and the work (Barewell, 1980). Useful shapes may be generated in four basic methods viz; deformation, casting, machining and powder metallurgy (DeGarmo *et al.*, 1979).

While casting processes exploit the fluidity of a liquid as it takes shape and solidifies in a mold, material removal processes (machining) provide excellent precision and great flexibility but tend to waste material in the generation of the removed portions. Deformation processes on the other hand exploit a remarkable property of some materials (usually metals) – their ability to flow plastically in the solid state without waste. Cast ingots (strands and slabs) are reduced in size and converted to basic forms such as sheet rods and plates. These forms may then experience further deformation to produce wire or other finished products (DeGarmo *et al.*, 1979).

Metal deformation consists of both hot working and cold working operations. In general, an increase in temperature brings about a decrease in material strength, an increase in ductility, and a decrease in the rate of strain hardening – all effects would tend to promote ease of deformation. Hot working is under conditions of temperature and strain rate such that recrystallization is occurring simultaneously with deformation. Generally, the temperature of deformation must exceed 0.6 times the melting temperature on the absolute (Kelvin) temperature scale (DeGarmo *et al.*, 1979).

When the deformation is carried out at higher temperature, two main advantages are obtained; the metal is softer requiring less force and consequently lighter equipment and the recrystallization required for crystal grain refinement proceeds rapidly. The tensile strength and hardness of the homogenized metal can subsequently be increased by work-hardening in a cold-working operation, usually done at room temperature (Rowe, 1977). In cold working, recovery processes are not active; generally, in working temperatures less than 0.3 times, the work-piece melting temperature. In cold working, two factors are of prime importance (DeGarmo *et al.*, 1979).

(i) The magnitude of the yields stress, which determines the force required to initiate permanent deformation and,

(ii) The extent of the strain region which indicates the amount of plastic deformation or ductility to be utilized.

2.6 FRICTION AND LUBRICATION IN METAL WORKING

Whenever there is a relative motion between two bodies in contact, there is a resistance to this motion. This resistance is called frictional stress. It is encountered in plastic forming of metals between the die and the material. This friction resistance is denoted by τ and is measured in force per unit surface area of contact. The surface area of contact is a boundary of the deformed metal. The friction resistance is also the shear stress in the material at its boundary. In the process of plastic forming of metals, friction between the metal and the tool (dies) plays a critical part. Force, flow patterns, tool wear and surface finish of the product as well as the capacity of the equipment (in rolling) are all affected by friction (Evans and Avitzur, 1968).

2.6.1 Frictional effects in metal working

Friction effects are of importance from both practical and theoretical points of view in all types of manufacturing mechanical working operations in which a material is deformed by contact with rigid tools or dies. Frictional forces are generated at the interface between the tool and the deforming materials by virtue of the extension of the work-piece surface. These frictional forces exert the following effects (Espinoza-cantu *et al.*, 2008).

a. The load required for deformation is increased.
b. The surface internal structure and the surface characteristics (surface finish, surface defects) of the productions are affected.
c. Wear of the tooling is produced, thus reducing its useful life.
d. Dimensional changes occur in the material.

Due to these effects, friction is considered to be a major variable in metal working operations and must be controlled to optimize processing procedure to achieve economical goals without impairing the surface quality, the desired geometry or the internal structure of the product (Espinoza-cantu *et al.*, 2008). It should be noted that friction under metal working conditions is significantly different from that encountered in most mechanical devices. The friction condition of gears, bearing, journals and similar components generally involve (DeGarmo *et al.*, 1979);

1. Two surfaces of similar material and strength.
2. Elastic loads such that neither body undergoes permanent change in shape.
3. Wear-in cycles to produce surface compatibility.
4. Generally low to moderate temperature.

Metal forming operations on the other hand, involve a hard, non deforming tool interacting with a soft work-piece at pressures sufficient to cause plastic flow in the weaker material (DeGarmo *et al.*, 1979).

Friction between the interacting tool and work-piece generally raises the forces and power requirements, subjects the tool to higher pressures, renders deformation less uniform within the work-piece, raises the temperature of the interface and may set limit to the maximum deformation obtainable. Consequently, attention has always been given to the problem of providing low values of friction coefficient which can be achieved by proper lubrication. Lubrication is of immense importance during metal forming (DeGarmo *et al*, 1979). Lubrication provides smoother motion between work-piece and tools, thus reducing the energy required for a specific amount of deformation. The major function of a lubricant is to prevent metal pick-up and reduce both friction and wear by providing a film which separates the contacting surfaces (Rowe, 1978). Other consideration selecting a metal working lubricant include its ability to act as a thermal barrier, keeping heat in the work piece and away from the tooling, its ability to act as a coolant and remove heat from the tool, its ability to retard corrosion if left on the formed product, ease of application and removal, lack of toxicity, odor and flammability, reactivity or lack of reactivity with material surface, adaptability over a useful range of pressure, temperature and velocity, surface wetting characteristics, cost, availability and its ability to flow or thin and still function(DeGarmo *et al.*, 1979).

In addition the behaviour of a given lubricant will change with variation in the interface conditions. The exact response will depend on such factor as the finish on both surfaces, area of contact, load, speed, temperature and the amount of lubricant (DeGarmo *et al.*, 1979).

2.7 Mechanism of lubrication in metal working

The mechanism of lubrication is most readily specified in terms of the thickness of the lubricating film. Qualitatively, the lubricant can provide complete separation and low friction by a thick film of fluid (hydrodynamic lubrication) or thinner fluid films (thin film lubrication), molecular layer absorbed on the metal surfaces (boundary lubrication), surface films formed through a chemical reaction (extreme pressure lubrication) as well as solids deliberately interposed to perform a lubricating function (Schey, 1970).

2.7.1 Boundary Lubrication

Owing to high pressure and low speeds in most metal forming operations, lubrication is of the boundary type. As the lubricating film is made extremely thin by high local loads or by extension of surfaces, an exceedingly thin layer of perhaps molecular dimensions can remain to separate contacting surfaces. In such situations, bulk properties of the lubricant (such as viscosity) are of little importance, but the chemical constitution of the lubricant and that of the underlying metal assume great significance. In metal working processes, bulk deformation of the work-piece produces chemically reactive, new (virgin) surfaces which must be lubricated to avoid adhesion.

An effective way of accomplishing this objective is to interpose boundary lubricants in the vital interface between tool and work-piece. Extremely thin boundary film prevents the disastrous consequence of metal – to – metal contact, which will lead to achieving efficient metal deformation.

To provide sufficient adherence to the metal surface for effective boundary lubrication, polar lubricants such as fatty oil, fatty acids, soaps and waxes are used. The molecules of the polar substances in boundary lubricants have long carbon chains with one or more chemically active groups (polar groups) which adhere strongly to the work metal and tool causing the long carbon chain to be oriented approximately at right angles to the metal surfaces. These oriented films of polar substances (sometimes called oiliness agents, and are usually several atoms thick), minimize friction and metal to metal contact (Obi and Oyinlola, 1996).

2.8 Attributes of metalworking lubricant

There are many, often contradictory, attributes required of a good metalworking lubricant. It must be capable of functioning over a wide range of pressure, temperature, and sliding velocities. Since one of the characteristics of most plastic working processes is the generation of a large amount of new surface area, the lubricant must have favourable spreading and wetting characteristics. It must be compatible with both the die and work-piece material with regard to wetting and chemical attack. It should have good thermal stability and resistance to bacteriological attack and minor contaminants. A good lubricant produces a harmless residue that does not cause staining on subsequent heat treatment or welding, and which is easily removed. Finally, a lubricant should be nontoxic, free of fire hazard, and inexpensive (Dieter, 1988).

2.9 WIRE DRAWING OPERATION

Drawing operations involve pulling metal through a die by means of a tensile force applied to the exit side of the die. Most of the plastic flow is caused by compression force which arises from the reaction of the metal with the die.(Dieter, 1988 and McGannon, 1970).Usually the metal has a circular symmetry, but this is not an absolute requirement. The reduction in diameter of a solid bar or rod by successive drawing is known as bar, rod, or wire drawing, depending on the diameter of the final product. When a hollow tube is drawn through a die without any mandrel to support the inside of the tube, this is known as tube sinking. When a mandrel or plug is used to support the inside diameter of the tube as it drawn through a die, the process is called tube drawing. Bar, wire, and tube drawing are usually carried out at room temperature. However, because large deformations are usually involved, there is considerable temperature rise during the drawing operation (Dieter, 1988).

It is important in commercial wire drawing practice, to achieve the maximum number of reduction with the minimum number of passes (McGannon, 1970).

The main components required in wire drawing are the die, the die holder, the chuck and draw head. All these are usually arranged on a draw bench. To produce wires of a small diameter, dies of progressively decreasing diameters are placed in series. The cross section through a conical drawing die is shown in Fig. 2.1

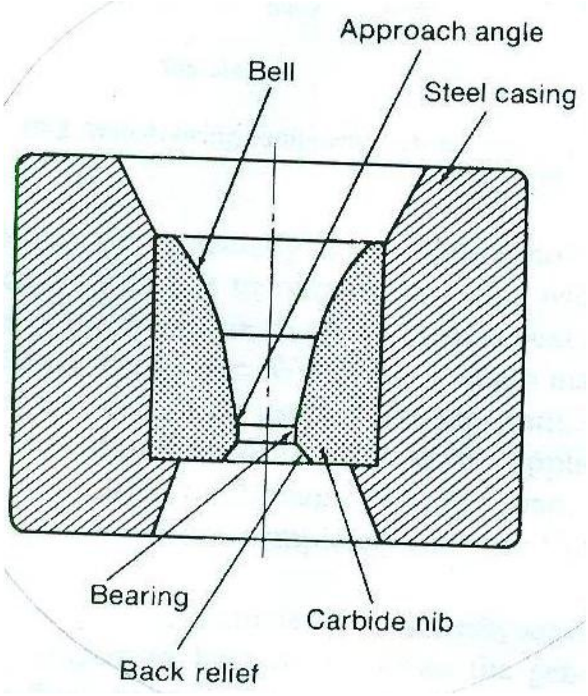


Fig. 2.1: Cross-section of a wire drawing die (Dieter, 1988).

The entrance of the die (the bell) is shaped so that the wire entering the die will draw lubricant with it. The shape of the bell causes the hydrostatic pressure to increase and promotes the flow of lubricant into the die. The approach angle is the section of the die where the actual reduction in diameter occurs. The half die angle α is an important process parameter. The bearing region does not cause reduction but it does produce a frictional drag on the wire. The chief function of the bearing region is to permit the conical approach surface to be refinished (to remove surface damage due to die wear) without changing the dimensions of the die exit. The back relief allows the metal to expand slightly as the wire leaves the die. It also minimizes the possibility of abrasion taking place if the drawing stops or the die is out of alignment. Most drawing dies are cemented carbide or industrial diamond (for fine wires). The die nib is encased for protection in a thick steel casing (Dieter, 1988).

The total tensile force necessary to draw the wire through a die is the sum of the forces needed to cause deformation of the metal by transverse compression and shearing and the force required to overcome friction between the wire and the die surface. Any increase in friction reduces the amount of deformation, which can be given to the wire in a single pass. It is therefore important that friction be reduced to a minimum by efficient lubrication and correct die design. The amount of reduction which can be achieved in a single pass through a die is limited by the tensile strength of the wire being drawn. High friction results in excessive metal flow in the vicinity of the interface and possible surface cracking and metal transfer to die (Obi, 2000). The friction coefficient in wire drawing is generally calculated from theoretical equation with known die geometry and drawing conditions. Different theories usually give different values (Oche, 1992).

The total force required for wire drawing is considered to depend on the following (McGannon, 1970); (i) die angle (ii) percentage reduction (iii) material flow stress (iv) die friction, which is a function of the die material, lubrication and drawing speed.

2.9.1 Mechanics of wiredrawing

Although wiredrawing appears to be one of the simplest metal working processes, a complete analysis that enables a better calculation of the draw force within the range of plus or minus twenty percent of the observed value is a rather difficult problem.

The uniform-deformation-energy method predicts a draw stress given by the equation below (Dieter, 1988),

$${}_{xa} = \; {}_{0}\,\mathrm{In}\, — = \quad \mathrm{In}\, —$$ ………………………………………………………………… 2.4

This equation not only neglects friction, but it neglects the influence of transverse stresses and of redundant (shearing) deformation.

In considering the problem of strip drawing operation where Coulomb friction coefficient μ exists between the strip and the die, the friction stress μp that ensues acts in the opposite direction of the motion of the strip through the die as shown in Fig 2.2.

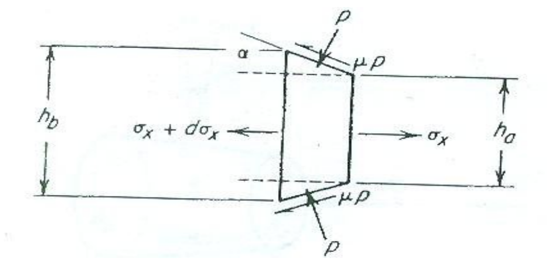


Fig 2.2: Stresses acting on elemental wire in plane-strain strip drawing (Dieter, 1988).

Resolving for the equilibrium of forces in the x direction, we have

$dh + hd \quad + 2p \tan\alpha\, dx + 2\mu p dx = 0$ 2.5

since $dh = 2dx \tan\alpha$,

$dh + hd \quad + p(1 + \mu \cot\alpha)\, dh = 0$ 2.6

The yield condition for plane-strain is $\quad + P = \sigma'_o$ and $B = \mu \cot\alpha$, hence, the differential equation for strip drawing is of the form;

$$\frac{\qquad\qquad}{(\qquad)} = \frac{\quad}{\quad}$$ 2.7

If B and $\quad'$ are both constant, equation 2.7 can be integrated directly to give the draw stress

$= \quad' \frac{\quad}{\quad} [1 - (\frac{}{})^B] = \quad' \frac{\quad}{\quad} [1 - (1 - r)^B]$ 2.8

Since wiredrawing operation is often conducted with conical dies and based on the analysis for wiredrawing (with conical dies) with friction (Johnson and Rowe), the surface area of contact between the wire and the die (Fig. 2.3) is given by;

$S = ——$ ……………………………………………………………………...………2.9

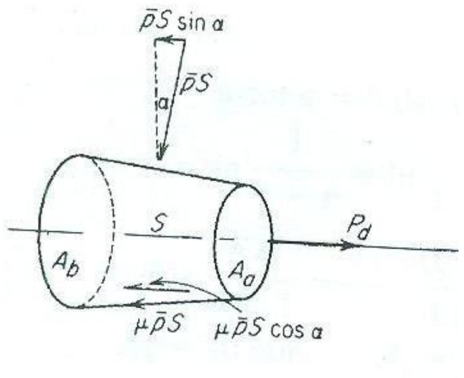


Fig. 2.3: Forces acting on a conical element (Dieter, 1988).

The mean normal pressure on this area is p. The forces acting in the axial direction are given in the diagram above. The draw force P_d is balanced by the horizontal component of the frictional force and the horizontal component of the normal pressure.

$P_d = \mu pS\ \cos \alpha + ps \sin \alpha$ ……………………………………………………………… 2.10

$P_d = pS (\mu \cos \alpha + \sin \alpha) = p ——\ (\mu \cos \alpha + \sin \alpha)$

$P_d = p (\quad - \quad) (\mu \cot \alpha + 1) = p(\quad - \quad)(1+B)$ ……………………………….…. 2.11

In the absence of friction, B = O and $P_d = p (\quad - \quad) = {}_o A_a \ln —$ ……………………. 2.12

Therefore, the draw stress with friction is given by

$$_{xa}= \frac{}{} = \ _{o}\ \ln \frac{}{}\ (1+B)\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.13$$

Equation 2.13 includes a term for uniform deformation energy and a term for frictional energy. The redundant deformation can be taken into consideration by including a factor Φ which allows for the influence of redundant deformation in raising the flow stress of the material.

$$_{xa}= \Phi \ _{o}\ \text{In} \frac{}{}\ (1+B)\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.14$$

The redundant work factor Φ is defined as

$$\Phi = f(\alpha, r) = \frac{^{*}}{}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.15$$

where $\epsilon *$= the "enhanced strain" corresponding to the yield stress of the metal which has been homogeneously deformed to a strain ϵ.

An alternative approach is to use upper-bound analysis to account for the redundant deformation by assuming simple but reasonable deformation regions (Dieter, 1988). Unfortunately, this leads to complex equations;

$$_{xa}= \frac{_{o}\ \{2f(\alpha)\ \text{In}\frac{}{} + \frac{}{\sqrt{}}\ (\frac{\alpha}{\alpha} - \cot\alpha) + 2\mu\ (\cot\alpha\ \{1\text{-In}\frac{}{}\}\ \text{In}\ \frac{}{} + \frac{}{}\}}{1+2\mu\ (L/R_a)}\ \ldots\ldots\ldots\ldots\ldots\ldots 2.16$$

Where f(α) = a complex function of semi- die angle

L= the length of the die land

R_b= the radius of the billet

R_a = the wire radius

2.9.2 Theoretical Analysis of Wire Drawing Test

A method for the evaluation of friction co-efficient for wire drawing through open dies was developed by Evans and Avitzur (1968). In this method, it is assumed that friction either obeys coulombs law or is a constant proportional to the flow stress of the material. If friction is assumed to obey coulombs law, then,

$\tau = \mu p$ ……………………………………………………..…………………………….2.17

implying that the tangential stress τ at any point is proportional to friction μ is taken as a constant for a given die and material under constant surface and temperature conditions, and is in dependent of velocity. If friction is assumed a constant, then

$\tau = m \ \frac{}{\sqrt{}}$ ……………………………………………….……………………………. 2.18

where the shear factor m is taken as a constant for a given die and material under constant surface and temperature conditions and also considered independent of velocity. For no friction m=0 and maximum possible friction is denoted by m=1.

Schematically presented in Fig. 2.4 is the nature of flow through converging dies.

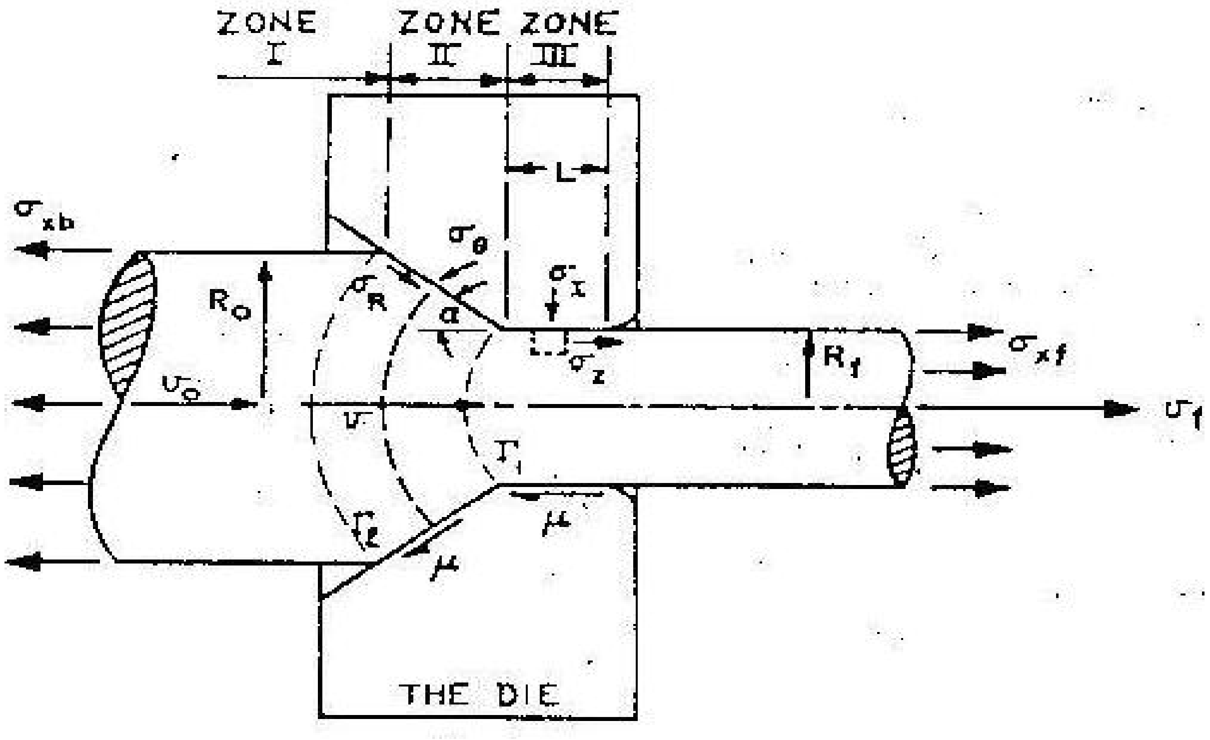


Figure 2.4: Flow through conical converging dies (Evans and Avitzur, 1968).

A wire of initial radius R_0 is pulled (drawn) through the conical portion of the dies. The cylindrical portion of the die causes friction though it is required for dimensional stability and also in line with die manufacturing practice. During flow through conical converging dies, the forces required for the drawing operation are dependent on the cone angle. There always exists an optimal cone angle which requires the minimum force. With an angle smaller than the optimal values, the drawing force is high because the length of contact between the die and material is high causing frictional losses; with a cone angle larger than the optimal, distortion is excessive leading to high forces (Evans and Avitzur, 1968).

The drawing stresses for wire drawing with assumption of coulombs friction and a constant shear factor are respectively given as,

—— = —— + 2 f(∝) In — + $\frac{}{\sqrt{}}$ ($\frac{\propto}{}$ - $_{\propto}$cot∝) + 2μ[(cot ∝){1-—— - In—} In—+—] ….….. 2.19

1 + 2μ—

and

—— = —— + 2 f(∝) In — + $\frac{}{\sqrt{}}$ ($\frac{\propto}{}$ - $_{\propto}$cot∝) + m(cot∝) In— + m—] ……………………..... 2.20

where;

f(α) = —— [1-(cos∝) $\overline{1 - — \quad 2 \propto}$ $\frac{}{\sqrt{}}$ In $\frac{—}{— \propto — \propto}$] …………………….2.21

Differentiating equations (2.19) and (2.20) with respect to ∝ and equating the derivative to zero gives the relations of the semi die angle which gives the minimum drawing stress. Thus we have;

2 sin$\propto_{opt}$ {[$\overline{1 - — \quad 2 \propto}$ - (cos∝opt) f (∝ })In — + $\frac{}{\sqrt{}}$ (1 - $\frac{\propto \quad \propto}{\propto}$)- μ (1- —— - In—)In —} = 0……………………………………………………………………….. 2.22

and

2 sin∝opt [$\overline{1 - — \quad 2 \propto}$ - (cos ∝opt) x f (∝ })In — + $\frac{}{\sqrt{}}$ [2(1-∝opt cos∝opt) – m In—] = 0…………………………………………………..…………………………2.23

With assumption of coulombs coefficient of friction, the frictional value for drawing was found to be

$$\mu = \frac{2\ (\sin\propto opt\ [\ \overline{1 - -\qquad 2\propto}\ - (\cos\propto opt)\ f\ (\propto\qquad]\ )\ In - + \frac{}{\sqrt{}}(1 - \frac{\propto\qquad\propto}{\propto})]}{(1 - \text{—} - In\ \text{—})\ In\ \text{—}} \quad \text{……......2.24}$$

With assumption of constant shear, the frictional value for drawing is

$$m = 2[\frac{(\propto}{-} \overset{\propto}{+} \sqrt{3}\ )(\sin\propto opt)\ x\ [\ \overline{1 - -\qquad 2\propto}\ - (\cos\propto opt)\ f\ (\propto\qquad]\ ) \text{……..2.25}$$

2.10 ROLLING OPERATION

The process of plastically deforming metal by passing it between rolls is known as rolling. This is most widely used metal working process because it lends itself to high production and close control of the final product. In deforming metal between rolls, the work is subjected to high compressive stresses from the squeezing action of the rolls and to surface shear stresses as a result of the friction between the rolls and the metal. The frictional forces are also responsible for drawing the metal into the rolls (Dieter, 1988).

In conventional hot or cold rolling, the main objective is the decrease in thickness of the metal. Ordinarily, little increase in width occurs, so that the decrease in thickness results in an increase in length. Cold rolling is used to produce sheet and strip with superior surface finish and dimensional tolerances compared with hot-rolled strip. In addition, the strain hardening resulting from the cold reduction may be used to give increased strength (Dieter, 1988).

In cold rolling, as strip is reduced and elongated, it changes speed relative to the roll and must slide against the roll surface. The resultant friction produces forces which tend to retain the strip in the roll bite, making the roll force and torque to increase with increase in friction.

A decrease in friction is thus desirable to reduce power consumption and roll load, and to obtain increased strip reduction. The later is of practical importance in the rolling of thin plate where the high load required causes considerable roll flattening (Usman, 1989). This increases the friction forces until a point is reached where no further strip reduction can occur. Reduction of friction hence will increase this limiting reduction, enabling the strip to be rolled. A high reduction per pass is required in cold rolling to reduce the number of passes needed for a given total reduction in thickness of a material. However excessive reduction per pass is likely to impair surface finish of the material owing to local breakdown of the lubricant. Good lubricants will not breakdown and therefore permit high reduction per pass without any detriment to the surface finish.

Elimination of the possibility of the damage caused by metal transfer from work piece to the tools is important. Tool life can be prolonged both by reducing friction and preventing metallic contact with the work piece. If the lubricant film is too thick, a matt surface may result. To produce a bright surface, it may be necessary to sacrifice some lubricating efficiency. Some operation however requires a certain minimum friction. In rolling of flat strip for example, the rolls will skid if friction is too low and it is necessary to use a relatively poor lubricant to obtain the greatest possible reduction in area per pass. Apart from increasing external forces, frictional stress has an important influence on metal flow, and may cause serious inhomogeneity in the worked product, as well as surface cracks and other defects.

2.10.1 Forces in rolling

Fig. 2.5 illustrates a number of important relationships between the geometry of the rolls and the forces involved in deforming a metal by rolling.

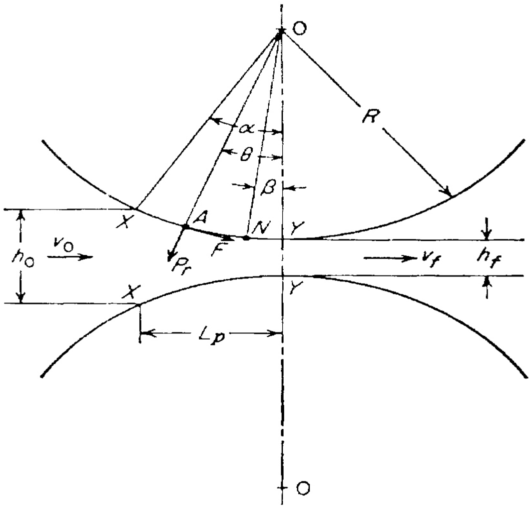


Fig. 2.5: Forces acting during rolling (Dieter, 1988).

A metal sheet with a thickness h_0 enters the rolls at the entrance plane XX with a velocity v_0. It passes through the roll gap and leaves the exit plane YY with a reduced thickness h_f. To a first approximation, no increase in width results, so that the vertical compression of the metal is translated into an elongation in the rolling direction Equal volumes of metal must pass a given point per unit time, hence

$bh_0v_0 = bhv = bh_fv_f$……………………………………………………………………..2.26

where

b = width of sheet

v = its velocity at any thickness h intermediate between h_0 and h_f

In order that a vertical element in the sheet remains undistorted, equation 2.26 requires that the exit velocity v_f must be greater than the entrance velocity v_0. Therefore, the velocity of the sheet must steadily increase from entrance to exit. At only one point along the surface of contact between the roll and the sheet is surface velocity of the roll v_r equal to the velocity of the sheet. This point is called the neutral point, or no-slip point. It is indicated in fig. 2.5 by point N.

At any point along the surface of contact, such as point A, two forces act on the metal. These are a radial force P_r and a tangential friction force F. Between the entrance plane and the neutral point the sheet is moving slower than the roll surface, and the frictional force acts in the direction shown so as to draw the metal into the rolls. On the exit side of the neutral point, the sheet moves faster than the roll surface. The direction of the frictional force is then reversed so that it acts to oppose the delivery of the sheet from the rolls.

The vertical component of P_r is known as the rolling load P. The specific roll pressure p is the rolling load divided by the contact area. The contact area between the metal and the rolls is equal to the product of the width of the sheet b and the projected length of the arc of contact L_p.

$$= \qquad h - h \qquad \rule{3em}{0.4pt} \qquad \approx \qquad h - h \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2.27$$

Therefore, the specific roll pressure is given by

$$= \rule{2em}{0.4pt} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2.28$$

The distribution of roll pressure along the arc of contact is indicated in Fig. 2.6.

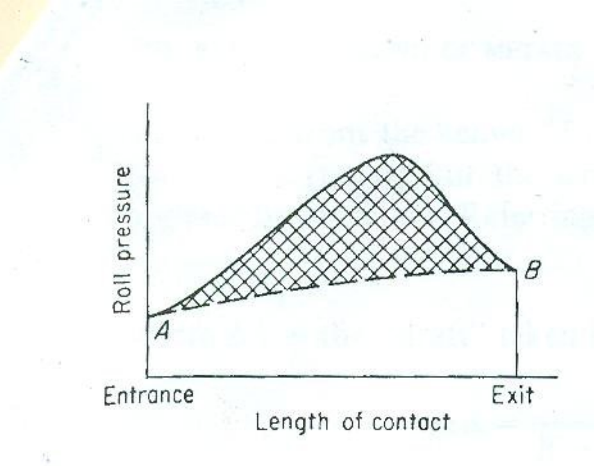


Fig. 2.6: Roll pressure distribution along the length of arc (Dieter, 1988).

The pressure rises to a maximum at the neutral point and then falls off. The fact that the pressure distribution does not come to a sharp peak at the neutral point, as required in theoretical treatments of rolling, indicates that the neutral point is not really a line on the roll surface but an area. The area shown shaded in Fig. 2.6 represents the force required to overcome frictional forces between the roll and the sheet, while the area under the dashed line AB represents the force required to deform the metal in plane homogenous compression.

The angle α between the entrance plane and the centerline of the rolls is called the angle of contact, or angle of bite. Referring to Fig. 2.5, the horizontal component of the normal force is P_rSinα, and the horizontal component of the friction force is Fcosα. For the work-piece to enter into the throat of the roll, the horizontal component of the friction force, which acts toward the roll gap, must be equal to or greater than the horizontal component of the normal force, which acts away from the roll gap. The limiting condition for unaided entry of a slab into the rolls is

$$F\cos \alpha = P_r \sin \alpha \qquad 2.29$$

$\frac{}{} = \frac{}{} = \tan\alpha$…………………………………………………………………….2.30

But F = μP_r

Then, $\mu = \tan\alpha$ ………………………………………………………………………………2.31

The work-piece cannot be drawn into the rolls if the tangent of the contact angle exceeds the coefficient of friction. If μ=0, rolling cannot occur but as μ increases progressively larger slabs will be drawn into the roll throat. For the same friction conditions, a large-diameter roll will permit a thicker slab to enter the rolls than will a small-diameter roll. This is because the angle subtended from the centre of the roll to the entrance plane will be the same in both cases (tanα) but the lengths of the arcs of contacts will be appreciably different. Referring to Fig. 2.5, we have

$\approx \sqrt{\quad \Delta h}$ ……………………………………………………………………………...……..2.32

Where Δh= the “draft” taken in rolling

$\text{Tan}\,\alpha = \frac{}{\Delta} \approx \frac{\sqrt{\quad \Delta}}{\Delta} \approx \overline{\frac{\Delta}{}}$ ……………………………………………..…….2.33

Thus, $\mu \geq \tan\alpha = \overline{\frac{\Delta}{}}$

or $(\Delta h)_{max} = \mu^2 R$ ………………………………………………………..……………...2.34

2.10.2 Analysis of rolling load

The main parameters in rolling are the roll diameter, the deformation resistance of the metal as influenced by metallurgy, temperature, and strain rate, the friction between the rolls and the work-piece and the presence of front tension and/or back tension in the plane of the sheet.

The rolling load is given by the roll pressure times the area of contact between the metal and the rolls (equation 2.28). Neglecting friction for the moment, the pressure is the yield stress of the material and the area of contact is the projected area of the arc of contact times the width of the metal in the roll gap. From equation 2.28

$P = pbL_p = \ ' \ b\sqrt{\quad \mathit{\Delta} h}$……………………………………………………………2.36

For the usual situation of the plane-strain conditions the influence of friction on rolling can be introduced by considering analysis for the plane-strain compression of a slab. To a first approximation rolling is plane-strain compression in which a friction hill is generated. Thus, the mean deformation pressure is given by

$\frac{}{\ '} = -(e^{Q} - 1)$ ……………………………………………………………… 2.37

where $Q = \mu L_p/h$

h = the mean thickness between entry and exit from the rolls.

Referring to equation 2.28, the rolling load is given by $P = pbL_p$ and since $Lp \approx \sqrt{\quad \mathit{\Delta} h}$

$P = \frac{}{\sqrt{}} \quad [-(e^{Q} - 1)b\sqrt{\quad \mathit{\Delta} h}$…………………………………………….…………… 2.38

The factor $2/\sqrt{3}$ arises because flat rolling is a plane-strain situation, so that the flow stress should be the flow stress in plane strain.

The mean flow stress for a rolling process can be determined directly from a plane-strain compression test. For cold-rolling it does not depend much on the strain rate or roll speed. However, in hot-rolling changes in strain rate can produce significant changes in the flow stress of the metal (Dieter, 1988).

The neutral point is the location on the arc of contact where the direction of the friction forces changes (Dieter, 1988). From the entry plane to the neutral point, the friction force acts in the direction of roll rotation, while on the exit side of the neutral point, it reverses direction. If back tension is applied gradually to the sheet, the neutral point shifts toward the exit plane. The total rolling load *p* and torque M_T (per unit of width b) are given by (Dieter, 1988);

$- = \int \quad pdx$, and

$— = \int \quad (\mu pdx)\ R = \mu R \int \quad pdx = \mu R\ -$ …………………………………………….. 2.39

Thus, $\mu = —$ ……………………………………………………………………………….2.40

The minimum sheet thickness that can be rolled on a given mill is directly related to the coefficient of friction. Since friction coefficients are much lower for cold-rolling than hot-rolling, thinner-gage sheet is produced by cold-rolling. The thickness of the sheet produced on a cold-rolling mill can also decrease appreciably by increasing the rolling speed (Dieter, 1988). This is attributable to the decrease in friction coefficient with increasing rolling speed.

The presence of tension in the plane of the sheet can materially reduce the rolling load. Back tension may be produced by controlling the speed of the uncoiler relative to the roll speed and front tension may be created by controlling the coiler (Dieter, 1988). The effect of sheet tension on reducing roll pressure p can be shown simply from a consideration of the von Mises' criterion in plane strain (Dieter, 1988).

$$- \quad = \frac{}{\sqrt{}} \qquad \text{……………………………………………………………………… 2.41}$$

$$p - (- \quad) = \frac{}{\sqrt{}} \qquad \text{……………………………………………………………………… 2.42}$$

Where   is the horizontal sheet tension and compressive stresses are taken as positive.

$$p = \frac{}{\sqrt{}} \quad - \qquad \text{……………………………………………………………………… 2.43}$$

Thus, the roll pressure is reduced in direct proportion to the tension in the plane of the sheet. This results in less wear of the rolls and improved flatness and uniformity of thickness across the width of the sheet (Dieter, 1988).

2.10.3 Plane-strain compression test

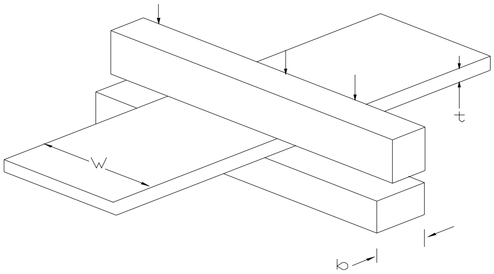


Fig. 2.7: Plane-strain compression test (Hosford and Caddel, 2007).

In the plane-strain compression test, gross plastic deformation of the stock occurs as in rolling (Guminski and Willis, 1960). When the strip is compressed, it lengthens but does not widen. The general procedure is to compress the test piece (of thickness t and width w) between the platens (of breadth b) with a given load and to measure the resultant reduction in thickness, the process being repeated for the various lubricants. The variation in thickness is assumed to be related to frictional condition produced by the various lubricants (Guminski and Willis, 1960).

2.10.4 Correlation of plane-strain compression test with rolling operation

The rolling operation can be treated as a two-dimensional deformation in thickness and length directions neglecting the width direction. This is due to the fact that the length of contact between the rolls and workpiece is generally much smaller than the width of the sheet passing through and the undeformed material on both sides of the roll gap is restraining the lateral expansion along the width direction. Spreading is prevented in the plane-strain compression test if w is much greater than b (Hosford and Caddel, 2007).

Practically, the value of w that is 10 times b is preferred to ensure that lateral spread is negligible (Rowe, 1978).

2.11 LOCAL VEGETABLE OILS UNDER INVESTIGATION

Tiger nut (known as Aya in Hausa) belongs to the genus cyperus with about 300 – 600 species (Olatunji, 2006). It is an ancient Egyptian crop which is today cultivated in West Africa, Spain and China.The tiger nut belongs to the specie cyperus esculentus or yellow nut sedge (Olatunji, 2006). Tiger nut oil has a golden brown colour and a nutty taste. The oil content is rich in gamma-tocopherol which means it is an oil with high resistance to oxidation and suitable for deep frying due to its high resistance to chemical decomposition at high temperature (tigernuts.com, 2008).

Neemseed oil is extracted from the plant azardirachta indica (known in Hausa as Dogonyaro tree) which originates from South East Asia. It is naturally abundant in most part of Nigeria and is presently used as pesticide and insecticides. Its potential as a quenchant has also been reported (Hassan *et al*., 2011).

False walnut (*Canarium schweinfurthii*) is the fruit of the perennial tree crop called "atili" in hausa and "ube okpoko" in ibo. The fruit is commonly found in large quantities in Pankshin, plateau state of Nigeria and is also produced in similar quantities in other states of the northern and south-eastern Nigeria(Agu *et al.*, 2008). The fruit pulp contains 30-50% of oil and is used for the manufacture of shampoo and bio fuels (Obame *et al.*, 2007).

Table 2.1: Fatty acid composition of neem seed and tiger nut oils

FATTY ACID			% IN INVESTIGATED OILS	
TYPE	CHAIN LENGTH	DOUBLE BOND	NEEM OIL*	TIGER NUT OIL **
Myristic	14	0	2.6	0.08
Palmitic	16	0	14.9	15.50
Palmitoleic	16	1	-	0.40
Stearic	18	0	19.1	5.4
Oleic	18	1	52.0	68.83
Linoleic	18	2	11.4	12.70
Linolenic	18	3	-	0.20
Arachidic	20	0	-	0.64
Gadoleic	20	1	-	0.23
Behenic	22	0	-	0.13
Lignoceric	24	0	-	0.19
PERCENTAGE SATURATION			36.60 %	21.94 %

*Shamagana (2008)

**Olatunji (2006)

CHAPTER THREE

3.0 MATERIALS, EQUIPMENT AND GENERAL EXPERIMENTAL PROCEDURES

3.1 Materials

The materials used in this research work are; commercially pure aluminum sheet, neem oil, tiger nut oil, false walnut oil; emery paper, methanol, ethanol, mild steel rods and cotton wool.

3.2 Equipment

The important equipment used in this study are 500 kN Denison testing machine and the 100 kN Universal materials testing machine.

3.3 Experimental procedures

The neem and tiger nut oils were obtained from NARICT, Zaria (a Governmental Research Institute that specializes in the extraction of various vegetable oils). The False walnut oil was purchased from open market in Jos, Plateau state.

3.3.1 Determination of fatty acid composition of false walnut oil and physical properties of investigated local vegetable oils

The fatty acid composition of false walnut oil was determined at NARICT, Zaria, while the viscosity, saponification value and the percentage free fatty acid values of the investigated local vegetable oils were determined at Chemical Engineering Department of Ahmadu Bello University, Zaria, Nigeria. The fatty acid composition of false walnut oil is presented in Table 3.1 while the physical properties of the investigated local vegetable oils are presented in Table 3.2.

Table 3.1: Fatty acid composition of false walnut oil

Fatty acid	Chain length	Double bond	Percentage (%)
Palmitic	16	0	53.01
Palmitoleic	16	1	0.64
Stearic	18	0	3.29
Oleic	18	1	27.25
Linoleic	18	2	15.81
Percentage saturation		56.30 %	

Table 3.2: Physical properties of the investigated local vegetable oils

Local oils	Viscosity (cP)		Saponification value(mg KOH g^{-1})	% Free Fatty Acid (as oleic acid)
	At 28^{o}c	At 40^{o}c		
Neem oil	123.1	75	180	0.15
Tiger nut oil	100.4	52	199	0.24
False walnut oil	110.6	63	202	0.17

3.3.2 Wire drawing test

The method of investigation employed in this work is based on the method earlier developed by Evans and Avitzur (1968) for the evaluation of friction co-efficient for wire drawing through open dies. In order to obtain the optimum die angle in this experiment, a 500 kN Denison testing machine was modified to act as a draw bench and the practical was conducted as follows;

For each lubricant test, five rods of 250 mm length were machined to entrance diameters of 6.5 cm, 6.7 cm, 6.9 cm, 7.1 cm and 7.3 cm to give 5,10,15,20 and 25% reduction respectively. The exit diameter was 6.35 mm. The dies used for this test have cone angles (in degrees) of 2.75^0, 6.50^0, 10.05^0, 30.40^0, and 44.65^0.

The rods were swagged to a length of 80 mm to allow gripping by the jaw of the Denison testing machine.

In the first test, the rod was lubricated by neem oil and pulled through the die with a die angle of 2.75^0 through a length of about 30 mm. After this, the rod was removed, relubricated with the same oil and pulled through the die with the next larger semi angle, i.e. 6.50^0 after which the rod was again removed and relubricated. The procedure was repeated for the remaining dies in order of increasing cone angles. The loads for each draw were recorded.

This procedure was repeated for all the three oils and sodium stearate in methyl alcohol which served as a standard basis for comparison of the individual oil's performance (Obi, 2000).

3.3.3 Plane-strain compression test

In this test, a strip, 40 mm wide, 1 mm thick and 150 mm long of commercially pure aluminum was used. The strip was thoroughly cleaned with ethanol to remove dirt and other contaminants from the surface. The surfaces of the platens were also cleaned with ethanol applied by rubbing with a filter paper until the latter remained unstained. This was done after the platens have been lightly rubbed with 600 emery paper to remove any pick up from previous tests. Neem oil under investigation was applied to the surfaces of both the strip and the platens by rubbing with the use of cotton wool. The strip was then placed between the operating surfaces of the platens (120 mm x 65 mm x 3 mm) fitted in the appropriate jig assembly and placed between the compression table of a 100 kN Universal Material Testing Machine. The platens were then loaded to 20 kN, held for few seconds and released. The strip was then advanced so that the undeformed material was between the tool, and the load applied again until five impressions were made. Using a micrometer screw gauge with modified sleeves, the thickness of the material was measured for all reduction and the average value was expressed as the percentage reduction.

This process was repeated for the other test oils (tiger nut and false walnut) as well as the paraffin lubricant which served as the standard.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

Table 4.1: Draw load for various die angles at different reduction in area under various lubrication conditions.

Lubricant	% Reduction	Draw load at various die angles (kN)				
		2.75°	6.50°	10.05°	30.40°	44.65°
Neem oil	5	6.9	6.3	6.6	8.1	----
	10	6.7	6.6	7.0	6.8	12.1
	15	8.1	7.5	7.1	10.65	15.2
	20	13.7	12.6	10.3	12.6	15.0
	25	15.4	14.25	13.35	17.4	18.6
Tiger nut oil	5	6.2	5.5	7.3	8.25	----
	10	6.35	5.8	9.1	11.1	----
	15	13.00	10.6	9.0	11.6	15.0
	20	13.4	11.8	10.9	13.8	15.2
	25	14.1	13.2	14.25	17.1	18.6
False walnut oil	5	5.6	5.1	5.5	7.1	----
	10	7.1	5.3	6.8	8.2	----
	15	11.8	9.3	9.1	9.35	12.3
	20	11.3	9.8	12.9	13.35	13.25
	25	12.9	11.65	13.5	15.6	18.0
Sodium stearate	5	5.6	3.35	10.95	12.7	15.0
	10	5.4	4.5	8.45	10.10	9.4
	15	7.65	7.0	12.3	15.7	15.85
	20	7.9	7.0	11.8	13.9	16.1
	25	13.8	13.8	13.2	14.0	17.6

Table 4.2: Draw stress for various die angles at different reduction in area under neem oil lubrication condition.

% reduction semi cone angle (degrees)	5%	10%	15%	20%	25%
	DRAWING STRESS (N/mm^2)				
2.75	217.849	213.113	255.735	432.541	486.214
6.50	198.906	208.377	236.793	397.811	449.906
10.05	208.377	221.006	224.636	325.195	421.491
30.40	255.736	214.692	336.245	397.811	549.357
44.65	-------	382.025	479.899	473.585	587.245

Table 4.3: Draw stress for various die angles at different reduction in area under tiger nut oil lubrication condition.

% reduction semi cone angle (degrees)	5%	10%	15%	20%	25%
	DRAWING STRESS (N/mm^2)				
2.75	195.748	200.484	410.440	423.069	445.170
6.50	173.648	183.120	334.667	372.554	416.755
10.05	230.478	287.308	284.151	344.138	449.906
30.40	260.472	350.453	366.239	435.698	539.887
44.65	-------	……..	473.585	479.899	587.245

Table 4.4: Draw stress for various die angles at different reduction in area under false walnut oil lubrication condition.

% reduction	5%	10%	15%	20%	25%
semi cone angle (degrees)	DRAWING STRESS (N/mm^2)				
2.75	205.220	224.164	372.554	356.767	407.283
6.50	161.009	167.333	293.623	309.409	367.818
10.05	173.648	214.692	287.308	407.283	426.227
30.40	224.164	258.893	295.201	421.491	492.528
44.65	--------	-------	388.340	418.333	568.302

Table 4.5: Draw stress for various die angles at different reduction in area under sodium stearate lubrication condition.

% reduction	5%	10%	15%	20%	25%
semi cone angle (degrees)	DRAWING STRESS (N/mm^2)				
2.75	176.805	170.491	241.528	249.421	435.698
6.50	105.767	142.076	221.006	221.006	435.698
10.05	345.717	266.786	388.340	372.554	416.755
30.40	400.967	318.881	495.686	438.855	442.013
44.65	473.555	296.750	500.421	508.315	555.673

Table 4.6: Evaluated coefficients of friction for various optimum die angles obtained under various lubrication conditions.

Lubricant	% Reduction (r)	Optimum die angle		Coefficient of Friction (μ)	Average Coefficient of Friction
		Degree	Radian		
Neem oil	5	9.5	0.1657	0.4654	0.23042
	10	9.75	0.1701	0.2202	
	15	10.25	0.1788	0.1621	
	20	11.5	0.2006	0.1570	
	25	12.25	0.2137	0.1474	
Tiger nut oil	5	8.05	0.1413	0.1518	0.19622
	10	8.5	0.1483	0.3727	
	15	10.5	0.1832	0.1702	
	20	11.05	0.1928	0.1450	
	25	12.0	0.2093	0.1414	
False walnut oil	5	7.0	0.1221	0.2525	0.12978
	10	7.2	0.1256	0.1199	
	15	8.5	0.1483	0.1114	
	20	5.58	0.1483	0.0857	
	25	9.0	0.1570	0.0794	
Sodium stearate	5	7.5	0.1308	0.2898	0.16108
	10	8.5	0.1483	0.1673	
	15	9.6	0.1647	0.1375	
	20	9.75	0.1701	0.1128	
	25	10.0	0.1744	0.0980	

Table 4.7: Metal deformation under plane-strain compression test with neem oil as lubricant

Impression	Initial Strip thickness (mm)	Final Strip thickness (mm)	Deformation in Plane Strain Test (mm)	Reduction Capacity (%)
1	1.00	0.5200	0.4800	47.00%
2	1.00	0.575	0.425	
3	1.00	0.53	0.470	
4	1.00	0.515	0.485	
5	1.00	0.555	0.445	

Table 4.8: Metal deformation under plane-strain compression test with tiger nut oil as lubricant

Impression	Initial Strip thickness (mm)	Final Strip thickness (mm)	Deformation in Plane Strain Test (mm)	Reduction Capacity (%)
1	1.00	0.495	0.505	50.50%
2	1.00	0.51	0.490	
3	1.00	0.485	0.515	
4	1.00	0.495	0.505	
5	1.00	0.490	0.510	

Table 4.9: Metal deformation under plane-strain compression test with false walnut oil as lubricant

Impression	Initial Strip thickness (mm)	Final Strip thickness (mm)	Deformation in Plane Strain Test (mm)	Reduction Capacity (%)
1	1.00	0.485	0.515	52.19%
2	1.00	0.485	0.515	
3	1.00	0.480	0.520	
4	1.00	0.475	0.525	
5	1.00	0.470	0.530	

Table 4.10: Metal deformation under plane-strain compression test with paraffin as lubricant

Impression	Initial Strip thickness (mm)	Final Strip thickness (mm)	Deformation in Plane Strain Test (mm)	Reduction Capacity (%)
1	1.00	0.620	0.380	41.10%
2	1.00	0.585	0.415	
3	1.00	0.625	0.375	
4	1.00	0.565	0.435	
5	1.00	0.550	0.450	

The draw loads obtained at different die angles are given in Table 4.1. From the applied drawing load of a given reduction under each lubrication condition, the draw stress was computed by dividing the applied drawing load by the cross-sectional area drawn during each test. On this basis, the computed draw stress (obtained from Equation 2.24) at various reductions under neem oil, tiger nut oil, false walnut oil and sodium stearate are given in Tables 4.2, 4.3, 4.4 and 4.5 respectively. Table 4.6 gives the values of the computed coefficient of friction under the various lubrication conditions. The results of the plane-strain compression test are presented in Tables 4.7-4.10 and Figure 4.6.

4.2 Discussions

4.2.1 Mild steel wire drawing operation under various lubrication conditions

In the present study, the value of the optimum die angle which gave the minimum drawing stress was used to assess the performance of the local oils under investigation in the wire drawing operation.

The curves of drawing stress against the semi-cone angle for neem oil, tiger nut oil, false walnut oil and sodium stearate are presented in Figures 4.1, 4.2, 4.3, and 4.4 respectively. A curve through the minimum points of the curves serves to identify the optimum die angles at the abscissas under the investigated oil lubrication conditions. Figure 4.5 give the variation of the coefficient of friction with percentage reduction.

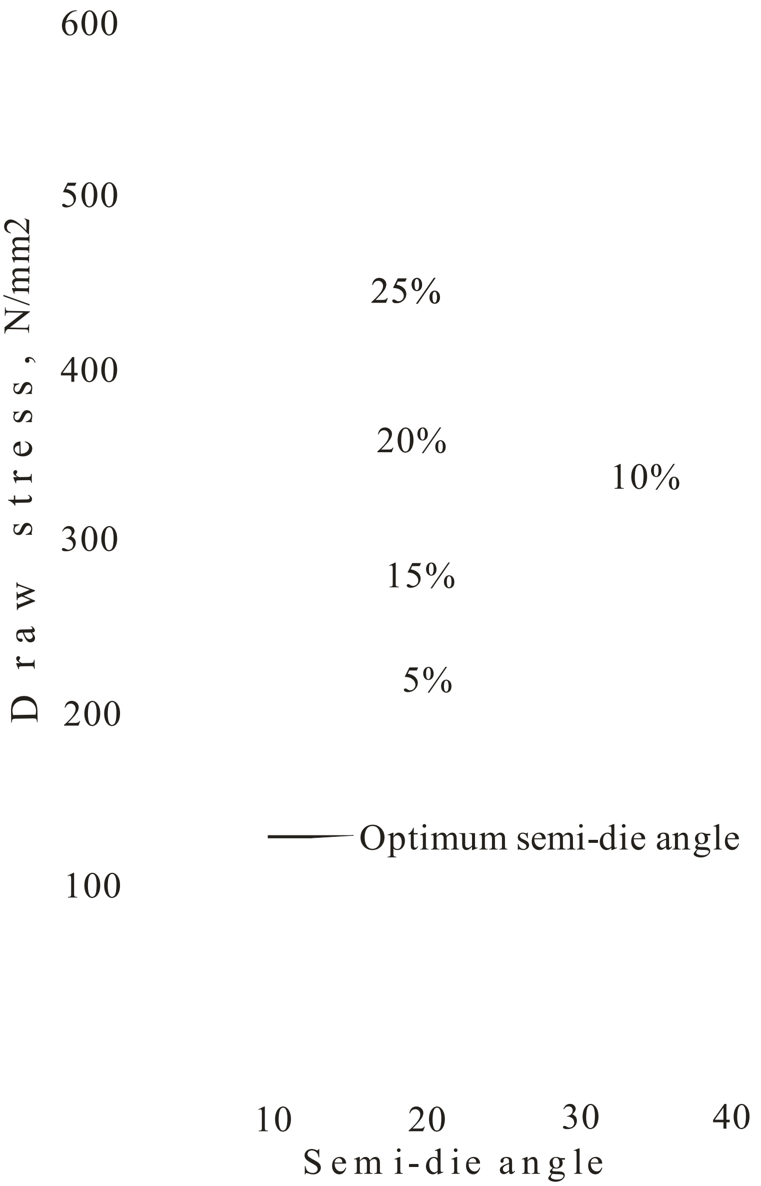


Fig. 4.1: Variation of draw stress with semi-die angle under neem oil lubrication condition

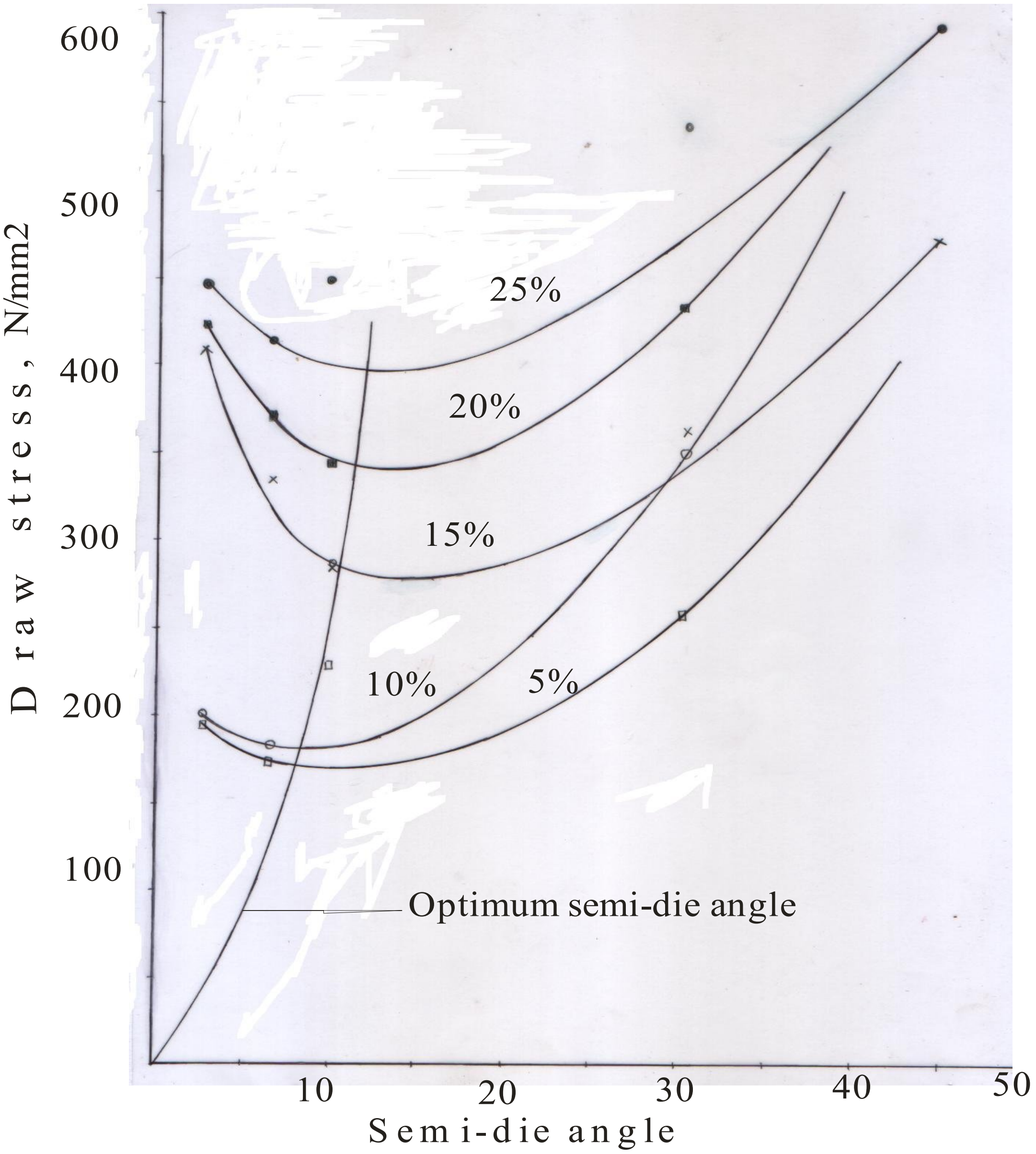


Fig. 4.2: Variation of draw stress with semi-die angle under tiger nut oil lubrication condition

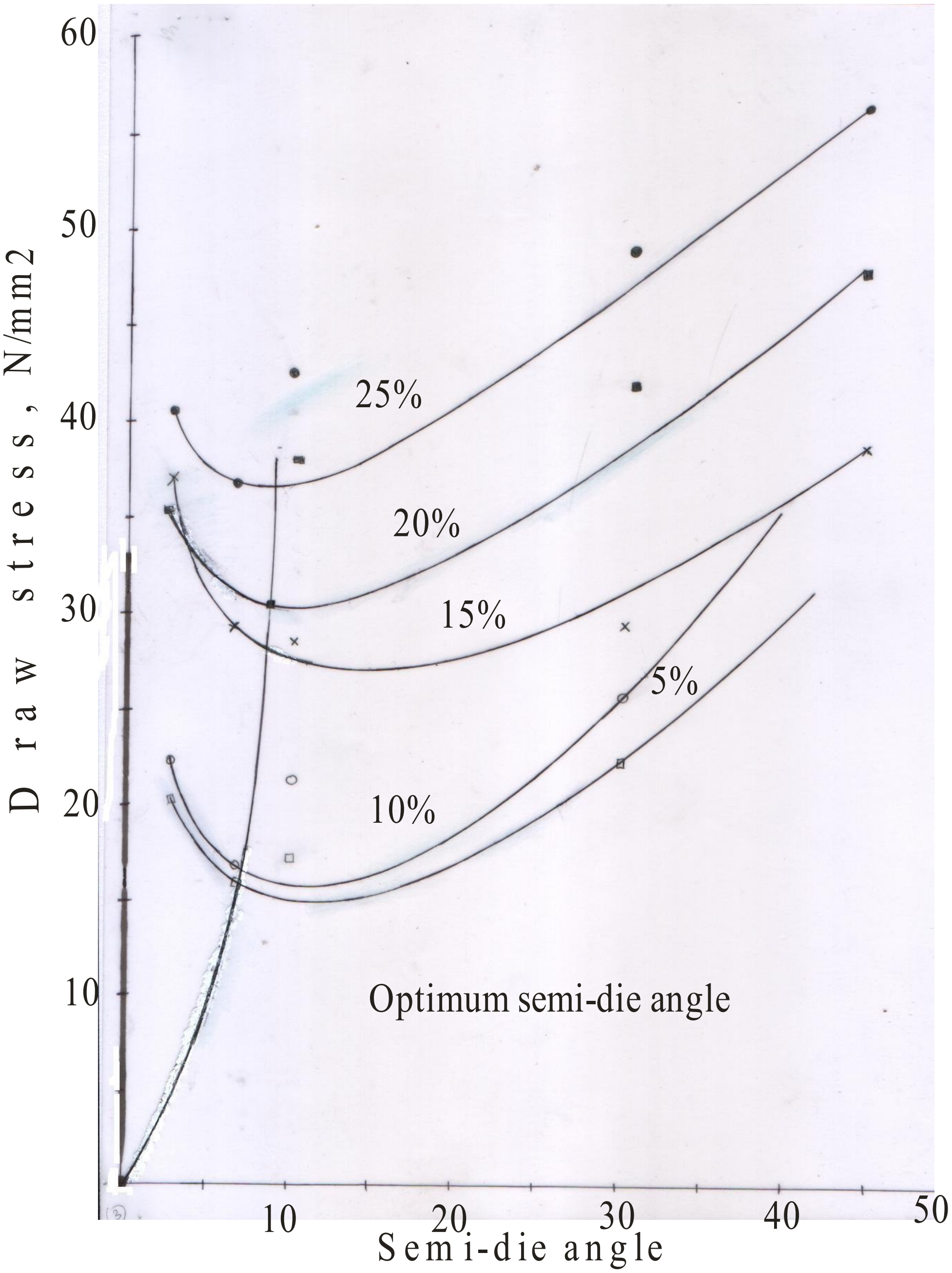


Fig. 4.3: Variation of draw stress with semi-die angle under false walnut oil lubrication condition

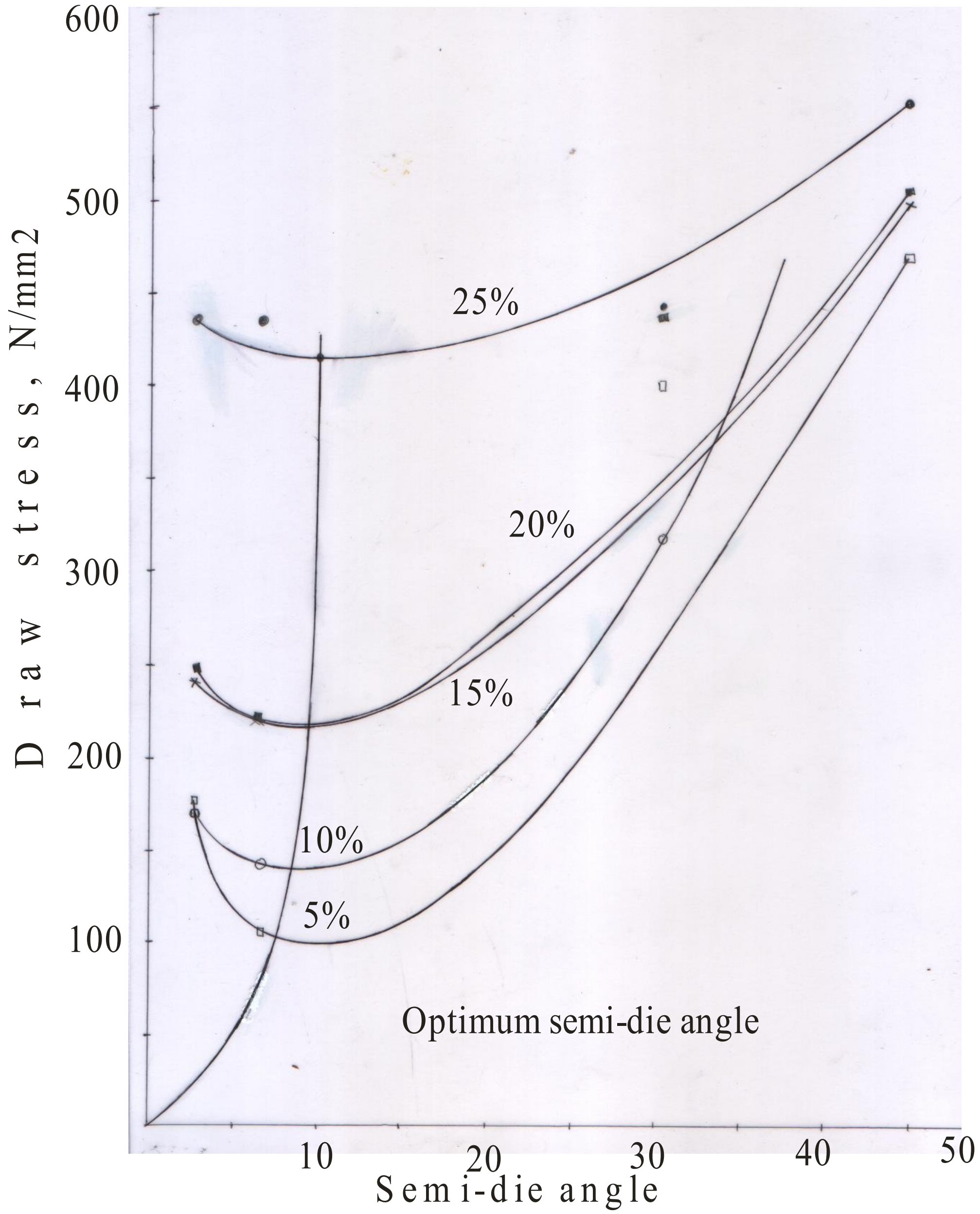


Fig. 4.4: Variation of draw stress with semi-die angle under sodium stearate lubrication condition

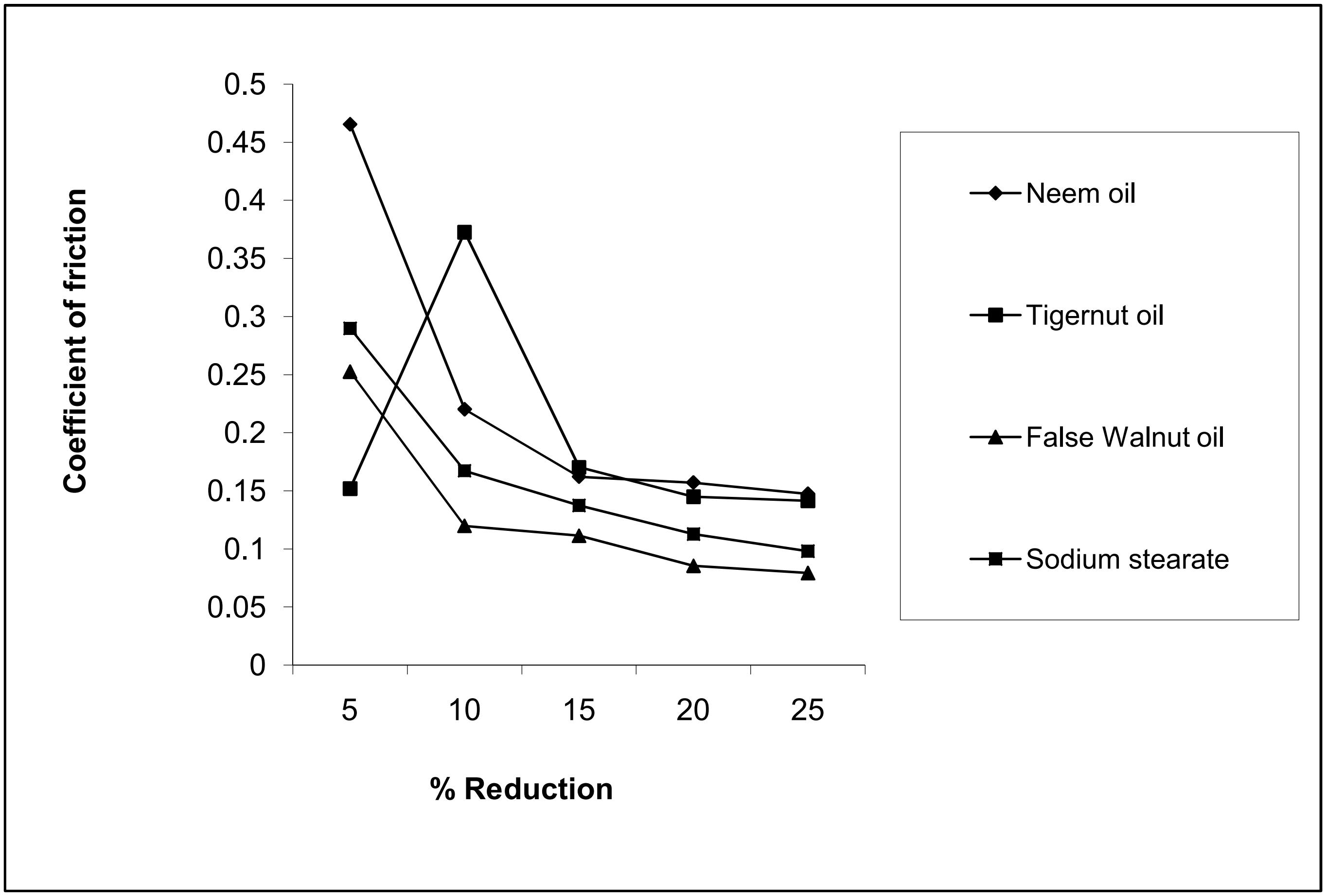


Figure 4.5. Variation of coefficient of friction with percentage reduction in area for the various lubrication conditions.

Generally, the coefficient of friction decreases with percentage reduction except for tiger nut oil which initially increase to 0.3727 at 10% and then reduces continuously afterwards. This trend was observed in previous studies (Oche, 1992) in the use of shea butter oil as lubricant for steel drawing. The presence of palmitic and oleic molecules as shown in Table 2.1, coupled with increase in temperature resulting from increase in percentage reduction which promotes fast reaction of the fatty acids with mating surfaces should have led to reduction in friction coefficient as the percentage reduction increases. The initial increase in the value of friction coefficient observed under tiger nut oil lubrication condition could be attributable to slow immediate response of its components to low temperature accompanying low percentage reduction in area since generally increase in temperature usually enhances the rate of reaction. In essence, any increase in deformation gives rise to increase in temperature which leads to faster reaction rate of fatty acid oils. Additionally, as the load increases, the thickness of the lubricant film decreases thereby exhibiting greater resistance to shear. Consequently, frictional force increases at a rate lower than the increase in load as previously reported (Obi, 2000). Among the investigated oils, false walnut oil gave the least friction coefficient at all reductions except for 5% reduction in tiger nut oil; it also performed better than the standard sodium stearate of all percentage reductions. The average coefficient of friction for the oil is 0.12978 while that of the standard is 0.16108.

Tiger nut oil gave an average friction coefficient of 0.19622 while neem oil gave an average friction coefficient value of 0.23042. The fatty acid compositions of the investigated local vegetable oils are presented in Tables 2.1 and 3.1 while some of their physical properties are presented in Table 3.2.

The high performance of the false walnut oil can be attributed to the fact that the oil contains high percentage (53.01 %) of palmitic acid. In addition to this is its higher amount of saturation (56.30%) that enhances better boundary lubrication condition. Tiger nut has lower percentage of saturated fatty acid but still performed better than the neem oil. The major limitation of unsaturated fatty acid is their low oxidative stability due to their breakdown at the bonds of unsaturation (Oche, 1992). Tiger nut oil is known to contain high amount of anti-oxidants which confer on it high stability. This stability might have given room for the unsaturated fatty acid components of the oil to improve its performance. Equally, its higher amount of free fatty acid and longer chain fatty acids such as gadoleic, behemic and lignoceric acids might have aided its efficient lubricating performance.

On the basis of viscosity, false walnut oil with a viscosity value (110.6 cp at 28^{o}c and 63cp at 40^{o}c) performed better than the tiger nut oil with a viscosity of 100.4 cp and 52 cp at 28^{o}c and 40^{o}c respectively. Neem oil has the greatest viscosity values of 123.1 cp and 75 cp at 28^{o}c and 40^{o}c repectively yet gave the least performance. The observed inconsistencies has attestified to the fact that the bulk viscosity of lubricants has no significant effect upon their boundary frictional behaviour as earlier established by Schey (1970).

The lubrication efficiency of the investigated oils followed the increasing order of their saponification value. Since saponification value is a measure of the mean chain length of the fatty acid as it follows that false walnut oil with the highest saponification value of 202 mg $KOHg^{-1}$ gave the lowest average friction coefficient. The saponification value of tiger nut oil is 199 mg $KOHg^{-1}$ and it performed better than the neem oil with a value of 180 mg $KOHg^{-1}$.

4.2.2 Plane-strain compression test of aluminum strip under various lubrication conditions

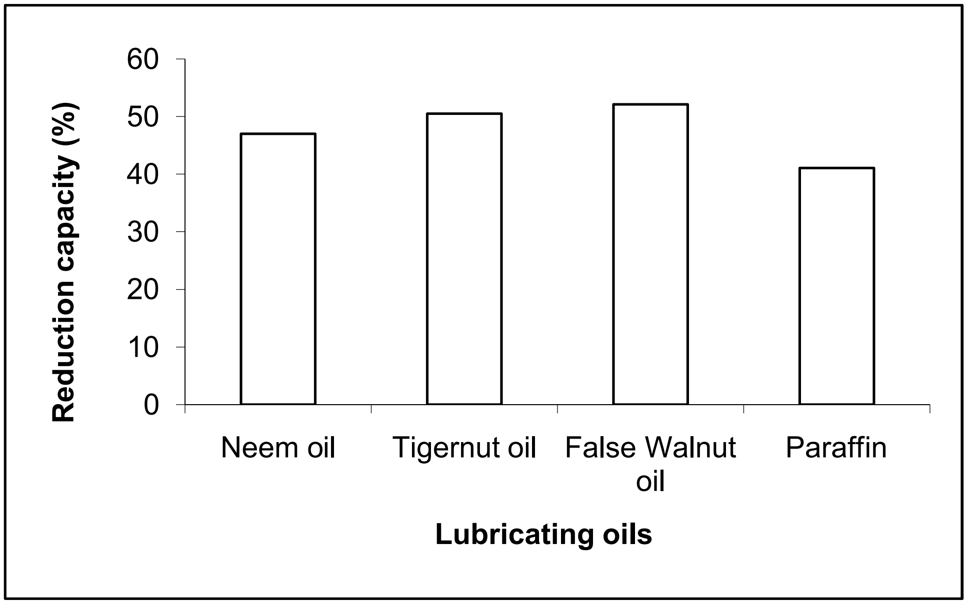


Figure 4.6 Bar graph showing the reduction capacity of the investigated oils under plane-strain compression test.

The results plane-strain compression test indicated that at a compressive load of 20 kN, all the investigated local oils gave better lubricating efficiencies than the paraffin lubricant-a standard lubricant used in cold working of aluminum. False walnut oil gave the highest percentage of 52.1%, followed by tiger nut oil with 50.5%, neem oil gave 47% while paraffin (kerosene) gave 41.1% reduction. The fatty acid contents of the investigated oils aided their performances under the plane-strain compression test condition. False walnut oil contains mainly saturated fatty acids (53.01 % of palmitic acid) and unsaturated fatty acids like oleic acid and linoleic acid (27.25% and 15.81 % respectively).

The high amount of palmitic (saturated) acid is responsible for the high reduction capacity under false walnut oil lubrication condition. Tiger nut oil contains higher amount of unsaturated fatty acids than neem oil yet it gave a higher reduction capacity. As previously explained in this work, the high content of anti oxidant it (tiger nut oil) contains might have prevented the breakdown of the unsaturated fatty acids thereby allowing them to improve the efficiency of the lubrication process. It was observed that the trends in the performances of the investigated local vegetable oils is similar for the processes of wire drawing and plane-strain compression test (used to simulate cold rolling operation) employed in this investigation. Lubrication in cold rolling is recognized to be of the mixed type with hydrodynamic and boundary elements both playing significant roles. Experiments have revealed that low reductions favour hydrodynamic lubrication while a high reduction favour boundary lubrication (Schey,1970). From the obtained results, it can be concluded that, though hydrodynamic lubrication mechanism might operate, the boundary lubrication mechanism predominates; hence the similarity in trends of performance as stated above.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The following conclusions can be drawn from the results of the research work.

1. Neem, tiger nut and false walnut oils have been adjudged suitable for use as lubricants in the drawing of mild steel based on the values of coefficient of friction obtained under their lubrication conditions.

2. All the three investigated oils assessed were found suitable for use as lubricants for cold rolling aluminum.

3. False walnut was evaluated to be the most suitable of the oils for both cold rolling of aluminum and drawing of steel.

4. The physicochemical properties of the oils aided their performance as boundary lubricants as revealed by the results emanating from the present research effort.

5.2 RECOMMENDATIONS FOR FURTHER STUDY

1. The effect of strain rate and temperature on the performances of the studied oils should be investigated.

2. The kinetics of lubrication of the oils during metal working operations should be studied for possible optimization of their performances.

3. The capacity of the oils to reduce wear should be investigated.

4. Tests should be carried for the possibility of using the oils under thick-film and extreme pressure applications.

5. The effect of elements such as calcium, phosphorus, chlorine e.t.c. (contained in the oils) on their performance should be investigated.

REFERENCES

Agwandas, A. A. (1988). Evaluation of Local Oils for Cold Rolling of Aluminium sheets. Unpublished B.Eng. Degree Project, Ahmadu Bello University, Zaria, Nigeria.

Agu H.O., Ukonze J. A. and Uchola N. O. (2008). Quality Characteristics of Crude Refined Atili Oils. *Pakistan Journal of Nutrition*, 7 (1): 27-30.

Alamu, O.J. (2007). Development and Evaluation of Palm Kernel Oil Biodiesel Fuel. *The Pacific Journal of Science and Technology,* 8(2): 212-219.

Aluyor E. O., Obahiagbon K. O. and Ori-jesu M. (2009). Biodegradation of Vegetable Oils: A Review. *Scientific Research and Essay*, 4 (6): 543-548.

Arnell, R.D., Davies, P.B., Halling, J. and Wholmes, T.L. (1991). Tribology: Principle and Design Applications. Macmillan Education Ltd, London, PP. 1-5, 27.

Metals Handbook (1978). Failure Analysis and Prevention., 8th Ed. American Society of Metals, Vol. 10.

Atawodi S.E. (2010). Polyphenol Composition and *in vitro* Antioxidant Potential of Nigerian *Canarium schweinfurthii* Engl. Oil. *Journal of Advances in Biological Research,* 4 (6): 314-322.

Barewell, F. T. (1980). Tribology in Metal Working, Developments in Perspective. Inst. Mech. Engrs., PP. 51-63.

Belewu M.A. and Abodurin O.A. (2006). Preparation of Kunnu from Unexploited Rich Food Source: Tiger Nut (*Cyperus esculentus*). *World Journal of Dairy and Food Sciences,* 1(1).

Biochemistry Department (2011): Laboratory Manual for BCHM 247.

Cheng, G. K., (1983). Function of Lubrication in Aluminium Foil Rolling. *Journal of Lubrication Technology,* vol.36: 87-92.

DeGarmo E. P., Black J. T. and Kohser R. A. (1990). Materials and Processes in Manufacture, 7th ed., Macmillan Publishing Company.

Dieter G. E. (1988). Mechanical Metallurgy, 3rd ed., McGraw-Hill Bok Company (UK) Ltd., London. PP. 586-600, 635-642.

Espinoza-cantu V., Guerrero-mata M. P., Lozano T. and Colas R.(2008). Evaluation of the Frictional Characteristics of Rolling Emulsions. *Ingenieria Mecanica Tecnologia Y Desarrollo*, 2(6): 200-204.

Evans W., Avitzur B. (1968). Measurement of Friction in Drawing, Rolling and Extrusion. *Journal of Lubrication Technology; Transactions of the ASME,* vol. 1: 72-80.

Fachagentur, N.R.V (2006). Report from the state of Germany. IENICA Project, PP. 7

Garrett, S. (1996). Vegetable Oil for Lubricating Chain Saws. U.S. Dept. of Agricultural Forest Service (Technology and Development Programme), PP. 1-3.

Gerulova K., Amcha P., Filicka S. (2010). Preliminary Ecotoxicity and Biodegradability Assessment of Metal Working Fluids. Research Papers; Slovak University of Technology in Bratislavia, No. 29: 17-27.

Halling, J. (1978). Principles of Tribology. Macmillan Education Ltd., London. PP. 1, 72-76, 95-113.

Hassan S. B., Agboola J. B., Aigbodion V. S. and Willims E. J. (2011). Hardening Characteristics of Plain Carbon Steel and Ductile Cast Iron Using Neem Oil as Quenchant. *Journal of Minerals and Materials Characterization and Engineering,* vol. 2: 161-172.

Hosford W. F. and Caddel R. M. (2007). Metal Forming Mechanics and Metallurgy. Cambridge University Press, New York. PP. 39.

Internet Link (2008). Tigernuts Oil Profile. Retrieved January 26, 2008, from http://www.tigernut.com/pdf/tigernuts.oil.profile.pdf.

Jayadas, N.H., Prabhakhram, K.N., Ajithkumar, G. (2007). Tribological Evaluation of Coconut Oil as an Environment Friendly Lubricant. *Tribology International*, vol. 40: 350-354.

Kalpakjian S. (1986): Recent Progress in Metal Forming Tribology. *Journal of Applied Metalworking,* 4 (3): 270-280.

Lloyd, L. (2003): How to Apply and Maintain Biodegradable Lubes. Machinery Lubrication Magazine.

Male, A. T. (1966). Variation in friction coefficients of metals during compressive deformation. *Journal of the Institute of Metals,* vol. 94: 121-125.

Male, A. T. and Cockcroft M. G. (1964-65). A Method for the Determination of the Coefficient of Friction of Metals under Conditions of Bulk Plastic Deformation. *Journal of the Institute of Metals,* vol. 93: 38-46.

McGannon, H. E. (1970). The Making, Shaping and Treating of Steel. United States Steel, 9th Ed., Herbick and Held, Pittsburgh, Pennsylvania.

Muhammad N. O., Bamishaiye E. I., Bamishaiye O. M., Usman L. A., Salawu M. O., Nafiu M. O. And Oloyede O. B. (2011). Physicochemical Properties and Fatty Acid Composition of Cyperus esculentus (Tiger Nut) Tuber Oil. *Bioresearch Bulletin*, vol. 5: 51-54.

Nelson J. (2000). Harvesting lubricants. The Carbohydrate Economy, Vol. 3 (1).

Nyior, G. B., (1994). Suitability of Local Oils for Cold Extrusion of Aladja ST60-2 Structural Steels. Unpublished M.Sc. Thesis, Ahmadu Bello University, Zaria, Nigeria.

Obame L.C.,Kaidou J.,Kumulungui B.S.,Bassole I.H.N.,Edou P., Ouattara A.S. and Traore A.S.(2007). Antioxidant and Antimicrobial Activities of *Canarium schweinfurthii* Engl. Essential oil from Central African Republic. *African Journal of Biotechnology*, 6 (20): 2319-2328.

Obi A.I.(2000). Lubricity Assessment of Vegetable Based Oils in Some Metal Forming Processes. Unpublished Ph. D Thesis, Ahmadu Bello University, Zaria, Nigeria.

Obi, A.I. and Oyinlola, A.K. (1996): Frictional Characteristics of Fatty based Oils in Wire Drawing. *Journal of Wear,* 194: 30-37.

Oche, O. J. (1992). Friction Coefficient in Wire Drawing Under Local Oils Lubrication Conditions. Unpublished B.Eng. Degree Project, Ahmadu Bello University, Zaria, Nigeria.

Olatunji A. (2006). Extraction and Characterization of Oil from Tigernut. Unpublished B.Eng. Degree Project, Federal University of Technology, Minna, Nigeria.

Oseni, M.I. and Nuhu, S. (2006). Rheological Behaviour of Wild Melon Oil Lubricant Blended with Transmission Oil. *Nigerian Journal Mechanical Engineering,* 4 (1): 95-108.

Roegiers M., Zhang H. and Zhmud B.(2008). Elektrionized Vegetable Oils as Lubricity Components in Metal Working Lubricants. *Faculty of Mechanical Engineering Transactions, Belgrade,* vol. 36: 133-138.

Rowe, G. W. (1978). Principles of Metalworking. Edward Arnold Press Ltd, London. PP. 1, 265-266, 277-279.

Schey J. A. (1970). Metal Deformation Processes: Friction and Lubrication. Mercel Decker Inc. New York. PP. 109, 121, 166-167.

Shamagana, Y.M. (2008). Suitability of Neemseed Oil Blends as Lubricant for Cold Extrusion of Mild Steel. Unpublished B.Eng. Degree Project, Ahmadu Bello University, Zaria, Nigeria.

Siniawski, M. (2006). Lubrication Research: Tribology and Energy System, Lecture notes. Loyola Marymount University, Los Angeles. PP. 4.

Stefanescu, I.I.,Camelia C., George C. (2002). On the Future of Biodegradable Vegetable Lubricants Used for Industrial Trybosystems. *The Annals of University "Dunarea De Jos" of Gallati,* PP. 94-98.

Szeri, A.Z. (1980). Tribology: Friction, Lubrication and Wear. Hemisphere Publishing Corporation, U.S.A. PP. 1, 427-457, 467.

Takahashi, H. and Alexander, J. M. (1961-62): Friction in the Plane Strain Compression Test. *Journal of the Institute of Metals*, vol. 90, Pp. 72-79.

Usman, Y.(1989): Assessment of Local Oils as Lubricants in Cold Rolling of Low-Carbon Steel Sheets. Unpublished B.Eng. Degree Project, Ahmadu Bello University, Zaria, Nigeria.

Willing, A. (2001): Lubricants Based on Renewable Resources–An Environmentally Compatible Alternative to Mineral Oil Products. *Chemosphere*, 43: 89-98.