POTENTIAL-ENHANCEMENT OF DEGRADED ENGINE OIL FOR FRICTION REDUCTION IN COLD UPSET FORGING OF ALUMINIUM ALLOYS

BY

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AUGUST, 2014

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Ibrahim USMAN, B. ENG. (MET.) (A. B. U.),2009

MSc/Eng./5559/2010-2011

A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES,
AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A
MASTER'S DEGREE IN METALLURGICAL AND MATERIALS ENGINEERING

DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING,
FACULTY OF ENGINEERING

AHMADU BELLO UNIVERSITY, ZARIA

NIGERIA

AUGUST, 2014

DECLARATION

I declare that the work in this Thesis entitled "Potential-Enhancement of Degraded Engine Oil for Friction Reduction in Cold Upset Forging of Aluminium Alloys" has been carried out by me in the Department of Metallurgical and Materials Engineering. The information derived from the 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 this or any other institution.

Ibrahim, USMAN
Name of StudentSignature Date

CERTIFICATION

This thesis entitled “Potential-Enhancement of Degraded Engine Oil for Friction Reduction in Cold Upset Forging of Aluminium Alloys” by Ibrahim USMAN meets the regulations governing the award of the degree of Master of Science (Metallurgical and Materials Engineering) ofthe Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

__________________________ Prof. A. K. Oyinlola Chairman, Supervisory Committee	____________________ Date
__________________________ Dr. G. B. Nyior Member, Supervisory Committee	____________________ Date
__________________________ Prof. S. A. Yaro Head of Department	____________________ Date
__________________________ Prof. H. Z. Hassan Dean, School of Postgraduate Studies	____________________ Date

DEDICATION

To my mum, late dad and big brother

ACKNOWLEDGEMENTS

Endless praise and deserving glory are due to Allah for bringing me thus far, despite the daunting challenges. Alhamdulillah!

I wish to start by acknowledging my supervisors; the enviable sage, Prof. A. K. Oyinlola, whose academic endowments are amazingly wonderful, and the amiable academic, Dr. G. B. Nyior for their guidance, criticisms, suggestions and patience with this humble protégé of theirs.

I also wish to appreciate the support of my head of department, Prof. S. A. Yaro and the entire staff of Department of Metallurgical and Materials Engineering, A.B.U., Zaria. The support of the departmental laboratory technicians,MallamShehuAliyuAbubakar and Mr. David Zang, and the humble gentleman, MallamMu’azu, of Strength of Materials laboratory, Department of Mechanical Engineering, A.B.U., Zaria is particularly appreciated.

Lastly, I wish to acknowledge the support and encouragement I enjoyed from my natal family back in Minna, extended family here in Zaria, friends and colleagues.

May Allah reward all manifold. Amin.

ABSTRACT

Enhancement of the friction-reducing properties of degraded 20W-50 engine oil by blending with neem and palm kernel oils respectively for application in cold upset-forging of aluminium alloys has been investigated using the ring compression test procedure. Three sets of blends of each of the vegetable oils with the degraded engine oil in the ratios 40:60, 50:50 and 60:40, the engine oil (unused and degraded) and the individual vegetable oils were investigated for friction reduction. Based on the modified empirical formula for friction coefficient determination under the various lubrication conditions, the average values of friction coefficient, μ obtained under the investigated unused engine oil, degraded engine oil, pure neem oil, 40% neem oil, 50% neem oil, 60% neem oil, pure palm kernel oil, 40% palm kernel oil, 50% palm kernel oil and 40% palm kernel oil oils were 0.073, 0.092, 0.068, 0.068, 0.062, 0.060, 0.057, 0.080, 0.058 and 0.057 respectively. Close correlations were observed betweencurves of these friction values andthe standard calibration curves proposed by Male and Cockroft. On comparative basis with degraded oil lubrication condition with average friction coefficient of 0.092, appreciable reduction in friction values were obtained. The lowest average was obtained under 60% palm kernel oil mixed with degraded engine oil. This is attributable to increased viscosity and fatty acid quantity/quality of the investigated vegetable oil. However, based on curves of plot of coefficient of friction against percentage reduction in height, 40% and 50% neem oil in degraded oil could be adjudged the best blend ratios as their coefficients of friction fall with increasing deformation, whereas most of the blends of palm kernel considered in this work demonstrated unstable trends. Best results for neem oil blends with degraded oil could be attributed to the favorable physicochemical properties of the parent vegetable oil.

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f	Friction force (Newton)
w	Normal load (Newton)
μ	Coefficient of friction
m	Friction factor
ΔD	Percentage reduction in diameter

CHAPTER ONE

1.0 INTRODUCTION

1.1 Preamble

Several countries in the world have put in place policies and plans to manage the disposal of degraded oil to protect their environment. Unfortunately the appropriate management of degraded oil is a common problem for many African countries, including Nigeria, where much of the wastes have negative environmental and human health risks because of inadequate systems for collection, storage, recycling, disposal etc. (Bamiro and Osibanjo, 2004).

A common trend in waste management in recent times is recycling of wastes. The benefits of recycling are: less waste, less pollution and a more prudent utilization of precious natural resources (Harrison, 1994). Recycling of used oils will not only reduce harmful wastes in the environment, but will also provide cheap alternative raw materials for industries, particularly the metal-based manufacturing industries.

In metal forming operations generally, friction has been identified as one of the important influential factors whose reduction is one of the main tasks in planning and realization of metal forming processes (Plancak*et al.*, 2012). Of all the methods currently available for reducing friction, the most effective and most employed way is lubrication of interfacial surfaces during deformation (Plancak*et al.*, 2012).

In conventional lubrication practices, the choice is often a mineral oil-based lubricant (Pettersson, 2006). Mineral oils used as lubricants have well-known properties and have been used as lubricants on a large scale since the end of the 19th century (Pettersson, 2006). Vegetable oils have also joined the list of lubricants in use in metalworking operations.

Prior to recent developments, vegetable and animal oils have functioned mainly as additives to mineral lubricating oil formulations (to provide lower friction and add to the load-carrying capacity of the formulation), although in some cases they are applied exclusively, or as blends for friction reduction purposes. For example, castor, peanut and rapeseed oils have been used in blends with mineral oils to improve lubrication performance (Aluyor and Ori-Jesu, 2008).

In this work, potentials of these vegetable oils in serving as either additives or blends in mineral lubricating oils have been explored in enhancing friction-reducing properties of degraded oils.

1.2 Statement of Research Problem

The high amount of waste lubricants generated in the country is a problem. Currently, more than 200 million litre of waste lubricants is generated per annum (Bamiro and Osibanjo, 2004). A part of these waste oils is re-used in lubrication of block making mould, gear oil production, hydraulic oil production, as anti-rust for metallic surfaces and locally as engine lubricant (Bamiro and Osibanjo, 2004), while the rest goes to the environment.

Researches have been carried out on a number of vegetable oils to evaluate their potentials as lubricants in metalworking operations. The thrust has been towards producing alternatives that are superior in properties to mineral oils and relatively cheap in cost. But, based on existing knowledge, not much has been reported on the use of degraded engine oil as lubricant in metalworking operations. The present work therefore investigated the possibility of enhancing friction reduction properties of degraded engine oil as lubricant for cold-upset forging of aluminum alloys by blending the degraded oil with neem and palm kernel oils respectively.

1.3 Justification

It is conceivable that within some of our lifetimes we will see the beginning of the end of the petroleum industry as we now know it. With that demise, we will see the end of lubricants derived from petroleum and the development of lubricants from other, more abundant materials (Szeri, 1980). Recognition of the limited nature of oil reserves and lack of environmental sound path of disposing the large quantity of degraded engine oil generated in the country – which is currently beyond 200 million liters per annum (Bamiro and Osibanjo, 2004) - prompted this research work to look at the possibility of enhancing degraded engine oil by blending it with some vegetable oils (palm kernel and neem oils) with the view of utilizing the blend in metalworking operations.

1.4 Aim and Objectives

The aim of this research is to evaluate the potentials of some vegetable oils (neem and palm kernel oils) in enhancing the friction-reduction property of degraded engine oil for application in cold forging of aluminium alloys.

Specific objectives of the work include:

1. To evaluate the coefficient of friction under lubrication conditions of neem oil, palm kernel oil and their respective blends with degraded engine oil by ring compression test.
2. To determine the effective blend ratio of the vegetable oils under study (neem and palm kernel oils) with degraded engine oil for cold-upset forging of Aluminium alloys.
3. To provide preliminary background information for further work on enhancement of degraded engine oil as lubricant in metal working operations

1.5 Scope

The scope of the research covered neem, palm kernel and Mobil Super XHP 20W-50 (unused and degraded) oils. The percentage deformation considered was from 20 to 50 in increments of 10%, and the compression test was carried out at room temperature. Blend ratios of the vegetable and degraded engine oils considered were, 40:60, 50:50 and 60:40. Properties of the oils such as Saponification value, Iodine value, Percentage free fatty acid and viscosity were measured.

1.6 Contribution to Knowledge

This research work has established the effectiveness of neem and palm kernel oils as suitable additives for enhancing the friction-reducing properties of degraded engine oil for use in cold-upset forging of aluminum alloys. This will help in maximizing the use of our limited petroleum resources.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Friction at the interface of die/work piece is an important variable and has significant effects on both the work piece and process variables such as deformation load, metal flow, surface quality, and internal structure of the product in metal forming processes(Rajesh and SivaPrakash, 2013). In essence, the interface friction has to be understood and controlled. For effective friction control, effect of lubrication, among other deformation process variables, has to be investigated. Such investigation of lubrication effect (or potential) of any lubricant in a particular metal forming operation would require a good understanding of tribology fundamentals and mechanics of metal forming.

2.2 Metal Forming

Metal forming is a manufacturing process in which the volume and mass of metal are conserved and the metal is displaced from one location to another (Dieter, 1988). Metal forming processes can be categorized into several groups based on the form of the applied stress (tensile, compressive, bending, or shearing), part to be formed (bulk, sheet), time-dependency (time-independent and dependent processes such as extrusion and upsetting), or forming temperature (cold, warm, hot forming). Hot forming has advantages of softening and recrystallization to make metal easier to form, while in cold forming, raising the strength of the product by strain hardening is possible. Cold forming may also permit higher geometric accuracy and surface finish by avoiding thermal problems such as oxidation and distortion (Cora, 2004).

2.3 Friction and Lubrication in Metal Forming

The resistance that is encountered when two bodies are rubbed against each other is called friction. Friction is an important factor in metal forming. It dissipates energy and hence increases the force needed to deform a material. It generates heat, which complicates the control of the deformation temperature. It can affect the material flow during deformation and lead to inhomogeneous deformation. Additionally, it can degrade the quality and appearance of the surface (Verlinden*et al.*, 2007). Based on these factors, it will be necessary in almost all forming operations to reduce the friction by adequate lubrication.

2.3.1 Friction in metal forming

Friction conditions at the die-material interface greatly influence metal flow, formation of surface and internal defects, stresses acting on the dies, and load and energy requirements. There are three basic types of lubrication that govern the frictional conditions in metal forming (Oh *et al.*, 1989):

I. Under dry conditions, no lubricant is present at the interface and only the oxide layers present on the die and workpiece materials may act as a "separating" layer. In this case friction is high, and such a situation is desirable in only a few selected forming operations, such as hot rolling of plates and slabs and non-lubricated extrusion of aluminum alloys.

II. "Hydrodynamic" conditions exist when a thick layer of lubricant is present between the dies and the workpiece. In this case the friction conditions are governed by the viscosity of the lubricant and by the relative velocity between the die and the workpiece. The viscosities of most lubricants decrease rapidly with increasing temperature. Consequently, in most practical high-speed forming operations, such as strip rolling and wire drawing, the hydrodynamic conditions exist only within a certain regime of velocities, where the interface temperatures are relatively low.

III. "Boundary" lubrication is the most widely encountered situation in metal forming. Increases in temperature at the interface and the relatively high forming pressures do not usually allow the presence of a hydrodynamic lubrication regime. In boundary lubrication, lubricants form surface layers, absorbed or chemically modified layers, and fill surface imperfections. The layers may undergo a dynamic process of 'rubbing off' and 're-generation'

2.3.2 Coefficient of friction

Interface friction may be characterized by coefficient of friction (Schey, 1970). 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).

Ranges of coefficient of friction for various metal forming operations are given in Table 2.1.

Table 2.1: Coefficient of Friction for Various Metal Forming Operations.

	Coefficient of Friction μ	
Process	**Cold**	**Hot**
Rolling	0.05-0.1	0.2-0.7
Forging	0.05-0.1	0.1-0.2
Drawing	0.03-0.1	–
Sheet-metal forming	0.05-0.1	0.1-0.2
Machining	0.5-2.0	–

Source: Cora, 2004.

2.4 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). Since metal forming induces high friction and heat generation between the tools and workpiece, lubrication is a critically important factor in reducing forming pressure and avoiding seizure in many forming processes (Matsumoto and Osakada, 2004).

2.4.1 Lubricants

Lubricants are used 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).

2.4.2 Common lubricants used in metal forming

A number of metal forming lubricants, in different forms, are in use. They are summarized as follows (Verlinden*et al.*, 2007):

I. Solid: Graphite {0.1–0.2; +450℃}, moly-di-sulphide (MoS2) {0.04–0.09; +400℃} and polymer (PTTE) {0.04–0.09; +250℃}. Respective friction coefficients and operating temperatures are mentioned within the brackets '{}'.

II. Semi-solid: *Greases*: Thickened mineral oils and synthetic oils with soaps (containing different metal ions – Na, Ca, Li, and Al). Adhesive/tacky: bitumen is the predominant substance.

III. Mixed or Partial Lubrication: Depending on relative stability of the boundary layer, mild or strong anti-wear additives are used.

Mild: Saturated/unsaturated fatty acids and primary/secondary alcohols.

Strong: Compounds of chlorine, sulfur or phosphorous.

IV. Fluid: From liquefied gasses to different types of oils and water. Most common are hydrocarbon-based mineral oils (80–85 wt%C and 10–15 wt%H) and synthetic lubricants. The former can be classified as paraffins, napthalenes and aromatics; while a range of esters, polyglycols, silicone oils, etc. are possible as synthetic fluid lubricants. Different additives are also used for improved performance and life.

2.5 Forging

Forging is a bulk deformation process in which the work is compressed between two dies (Marinov, 2013). As in metal forming, there are different classifications for forging such as in terms of temperature (hot, isothermal, warm and cold forging), die (open, closed-die), and shape (compact shapes, disk shapes, and long shapes) (Cora, 2004).

2.5.1 Cold forging

Cold forging is a process under which the bulk workpiece is placed between die and punch and subjected to compressive load. Forming temperature is below recrystallization temperature. Parts manufactured with the cold forming have better surface quality, and higher geometric accuracy, fatigue strength, ductility and improved grain structure (Cora, 2004).

2.5.2 Friction and lubrication in forging

In the simplest form of forging, pressure–temperature–velocity combinations change continuously, making formulation of any generalized velocity–stress–strain–friction distributions rather difficult. In open die upset forging(one of the simplest forms of forging) friction may change from sliding to sticking (or a combinations of the two), depending on the forging parameters and material aspects. For closed die forging, the frictional behaviour is more complicated and analytical solutions may exist only for the simplest geometries. Though the exact historical time frame for lubricant use in forging cannot be pin-pointed, the use of appropriate lubricants for frictional and other considerations is common in today’s forging technology (Verlinden*et al.,* 2007).

2.5.3 Cold forging lubricants

A number of lubricants are available for cold forging operations; these include mineral oils, animal oils, vegetable fats, soaps, waxes, graphite in water or oil, etc. (Verlinden*et al.*, 2007). The choice of any of the lubricants would be guided by some factors, such as: frictional issues, insulating properties, balanced gas pressure, surface wettability, non-abrasiveness and residues (Verlinden*et al.,* 2007).

2.6 Oils under Investigation

The oils under investigation in this work are: unused engine oil, degraded engine oil, palm kernel oil and neem oil.

2.6.1 Engine oil

Engine oils are made from crude oil and its derivatives by mixing of certain other chemicals (additives) for improving their performance in service (Abro*et al.,* 2013). Automotive lubricant oils are typically 75 to 85 percent base stock (i.e., crude oil-derived product) combined with performance enhancing additives. The base stock may consist of a mineral oil, synthetic oil, or a blend of both. The additives may contain zinc, magnesium, molybdenum, phosphorus, sulfur and bromine compounds. The base oil, in combination with the additives, determines the flow characteristics of the finished lubricant, its volatility and its oxidation stability (sludge and deposit-forming tendency) (Randles*et al.*, 2007).

Some of the grades of engine oil commercially available are Mobil Super XHP 10W-40, 15W-40, 15W-50 and 20W-50 (Exxon mobil, 2007).

2.6.2 Degraded engine oil

Used oil (or degraded oil) is defined as any oil that has been refined from crude oil, or any synthetic hydrocarbon oil, that has been used, and as a result of such use, has become unsuitable for its original purpose due to the presence of impurities or the loss of original properties (Alta'ani*et al.,* 2009). It includes used crankcase oil from automobiles and trucks, used industrial lubricating oils (such as metal working oils), and other used industrial oils (such as heat transfer fluids).

Lubricating oil serves a number of purposes in the engine. The lubricant protects automotive components by forming a wear-resistant film between moving surfaces, transports various protective chemical additives, and inhibits corrosion. Additives are blended into a lubricant base stock to provide desirable properties such as anti-wear, antioxidant and de-foaming capability and to inhibit corrosion. Engine oil performs under harsh conditions inside an engine with its combination of heat and high pressure, combustion activities and generation of chemical residues. In this harsh operating environment, the oil gets dirty, additives and other chemicals break down, and the oil requires regular changing (Randles*et al.*, 2007).

Degraded oil has been subject of concern over recent years. Studies have shown that a small quantity of used oil can cover a small lake and destroy the aquatic life in the lake (Alta'ani*et al.*, 2009). In large quantities, it can make water sources unfit for drinking purposes (Alta'ani*et al.*, 2009). The management options for used oil include re-refining, reprocessing, burning, road oiling, and disposal (Alta'ani*et al.*, 2009).

2.6.2.1 *Composition of degraded engine oil*

Degraded engine oils contain contaminating materials due to wearing and combustion, and their chemical compositions also differ from that of new oils due to oxidation and other chemical reactions. Most important contaminating materials in degraded engine oils include the following (Baladincz*et al*., 2008):

- Combustion products:

- Water: in case of a perfect process, engine fuel combusts into carbon monoxide and water. In normal operating conditions the steam vents through the exhaust system, though after cold-start a part of the arising water may mix with the engine oil thereby aiding the formation of sludge at the bottom of oil sump.

- Carbon black: in case of mainly diesel engines due to combustion, carbon black also forms, a part of which gets into engine oil.

- Engine fuel: a part of the non-combusted engine fuel accumulates also in engine oil.

- Contaminations originating from wearing:

- Metals: majority of metal particles coming from the cylinder wall and from the piston get into the engine oil. Particles such as: iron (400-800 mg/kg), chromium (30-50 mg/kg), copper (2-5 mg/kg), magnesium (150-400 mg/kg), nickel (2-7 mg/kg), calcium (600-2000 mg/kg), aluminium (300-800 mg/kg), arsenic (0-5 mg/kg) etc. Other part of the metals originated from additives that are originally in engine oil (e.g.: zinc dialkyl-dithio-phosphates). Such particles are the zinc particles.

- Dust: Dust and other solid contaminating materials (mainly silicates) get into engine oil through air filter and promote sludge formation.

- Oxidation products: lubricants contain also such molecules that oxidize due to heat load exercised in normal operating conditions within engine space; they form complexes with metals and compose organic acids.

- Halogenised hydrocarbons: total halogenic content of used engine oils is between 500-1000 mg/kg in general.

2.6.2.2 *Effects of contaminants on properties of engine oil*

Due to the contaminating materials present in relatively high amount, certain analytical and application properties of used engine oils change as well (Baladincz*et al*., 2008). The extent of this change is also affected by the composition of engine fuel (example, in case of diesel gas oils their vegetable oil fatty acid methyl ester content). Viscosity of used engine oils, for example, significantly decreases with the increase of engine fuel concentration (Baladincz*et al*., 2008).

Flash point significantly decreases by increasing the concentration of engine fuel especially in case of gasoline-driven engines. Flash point of engine oils of diesel-engines decreases in smaller extent by increasing the concentration of diesel gas oil, and the extent of decrease is also affected by the fatty acid methyl ester content of diesel gas oil (Baladincz*et al*., 2008).

Properties of used lubricants may differ significantly. The properties may complicate or hinder their recyclability. Brake oils and special oils (containing polychlorinated biphenyls which are carcinogenic) or synthetic oils are not recommended for blend and recycle together with other oils in high amount due to their properties (Baladincz*et al*., 2008).

2.6.3 Vegetable oils

Vegetable oils are obtained from renewable agricultural sources. They are also nontoxic and *have* excellent environmental and safety characteristics. These properties make vegetable oils attractive alternatives to petroleum-based oils in lubrication and other applications (Biresaw*et al.,* 2003).

Vegetable oils can be grouped into two broad chemical categories. Most vegetable oils are triesters of glycerol with various types of fatty acids and are commonly referred to as TG. A few vegetable oils are monoesters of long-chain fatty acids and fatty alcohols of varying degrees of unsaturation (Biresaw*et al.,* 2003).

Most vegetable oils can be considered to be amphiphilic since they comprise distinctly separated regions of polar and nonpolar groups in the same molecule. The polar groups constitute at least one ester functional group. The nonpolar groups are hydrocarbons of varying chain lengths, degrees of unsaturation, and stereochemistry. Depending on the type of vegetable oil, functional groups such as epoxides and hydroxides may be present in the hydrocarbon portion of the molecule. The tribological and other properties of vegetable oils are highly dependent on the exact chemical composition of its polar and nonpolar groups. For example, a triester of glycerol with a lower degree of unsaturation will have better oxidative stability than a triester of glycerol with a higher degree of unsaturation. Most vegetable oils are considered functional fluids since they have at least one functional group (an ester) and are also liquid at room temperature. This property allows vegetable oils to be used in lubricant formulations as base oils and/or boundary additives. Most lubrication processes occur in one of three lubrication regimes: boundary, hydrodynamic, and mixed. Vegetable oils, being functional fluids, can be used in all three regimes (Biresaw*et al.,* 2003). However, successful application of vegetable oils in lubricant formulations requires understanding the effect of vegetable oil chemistry on both their fluid and boundary properties (Biresaw*et al.*, 2003).

Two factors that affect the boundary lubrication properties of vegetable oils are adsorption and reaction (Biresaw*et al.,* 2003). Adsorption refers to the ability of the oil to adsorb onto friction surfaces and prevent their contact during a tribological process. Adsorption occurs mainly due to the interaction of the functional groups of the vegetable oils with the friction surfaces. Reaction deals with the tendency of the vegetable oils to undergo chemical reaction by themselves or with other materials (e.g., oxygen, moisture, metal) in the interface or friction zone. Reaction occurs owing to the high temperature, pressure, and shear of the lubrication process. These reactions, called tribochemical reactions, are poorly understood and are responsible for a number of phenomena such as degradation of the oil due to oxidation and the generation of friction polymers (Biresaw*et al.*, 2003).

Generally, the fatty acid type in vegetable oils plays a role in their lubrication. It is considered that the saturated fatty acid types (such as palmitic and stearic) are effective at lower temperature than the transition temperature for the corresponding soap films but unsaturated fatty acid types (such as oleic, linoleic and linolenic) preserve the low friction at high temperature range, probably due to tribochemical reactions (Murakami and Sakamoto, 2008).

2.6.4 Palm kernel oil

Palm kernel oil is gotten from the kernel of the palm fruit and it is located inside the hard shell while the outer fleshy mesocarp gives palm oil (Musa, 2009). Palm kernel oil is more unsaturated and hence can be hydrogenated to a wide range of products which could be used either alone or in blends with other oils for biscuit dough, filling creams, cake icing, ice cream, imitation whipping cream, substitute chocolate and other coatings, sharp melting and melting margarines etc. Mostly palm kernel oil is used for the manufacture of short chain fatty acids, fatty alcohols, methyl esters, fatty amines, for use in detergents, cosmetics and many other cosmetic products but less consideration is given it for other purposes (Musa, 2009). Its potential as a metalworking lubricant had been investigated previously (Oke, 1983; Abdulquadir and Adeyemi, 2008). Fatty acid composition of the oil is shown in Table 2.2.

2.6.5 Neem oil

Neemseed oil is extracted from the plant azardirachtaindica (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. It contains an appreciable amount of unsaturated fatty acids. Its potential as a quenchant has also been reported (Hassan *et al*., 2011). Gaminana (2011) also investigated its potentials as a metalworking lubricant. Fatty acid composition of the oil is shown in Table 2.2.

Table 2.2: Fatty Acid Composition of Neem and Palm Kernel Oils

Fatty Acids			Percentage In Investigated Oils	
Type	Chain Length	Double Bond	Neem Oil*	Palm Kernel Oil**
Myristic	14	0	2.6	16.2
Palmitic	16	0	14.9	8.4
Stearic	18	0	19.1	2.5
Oleic	18	1	52.0	15.3
Linoleic	18	2	-	2.3
Linolenic	18	3	11.4	-
Percentage Saturation			36.60	27.1

Sources:
*Shamagana (2008)
**Musa (2009)

2.7 Ring Compression Test

In most forming applications, the lubricity of a lubricant is the single most significant factor, since it directly determines the interface friction. In order to evaluate the performances of various lubricants and to be able to predict forming pressures, it is necessary to express the interface friction quantitatively, in terms of a factor or a coefficient (Oh *et al.*, 1989).

Lubricity (as defined by the friction coefficient) in cold forging processes is most commonly measured by the ring compression test developed by Male and Cockroft (Buschhausen*et al.*, 1992). In the ring test, a flat ring-shaped specimen is compressed to a known reduction. The change in internal and external diameters of the forged ring is very much dependent on the friction at the die-workpiece interface. If friction were zero, the ring would deform in the same way as a solid disk, with each element flowing radially outward at a rate proportional to its distance from the center. With increasing deformation, the internal diameter of the ring is reduced if friction is high, and is increased if friction is low. Thus, the change in the internal diameter represents a simple method for evaluating interface friction (Oh *et al.*, 1989). Figure 2.1 illustrates the test.

However, the interpretation of the geometrical changes of the ring in terms of friction values calls for a comprehensive analysis of the stress and strain distribution, unless some means of friction calibration can be applied in an empirical manner (Oke, 1983). A modified form of the empirical equation developed by Male and Cockroft (1964-65) suggested by Oyinlola (1976) can be used for friction calibration in upset ring compression test. For values of friction within the range μ = 0.055 - 0.57 and deformations between 20% and 60% (normal mechanical working conditions) the corrected equation can be expressed empirically in the form:

$$\Delta D = m \log_{10}(\frac{\mu}{0.055}) \qquad (2.3)$$

Where m is given by

$$\ln m = (0.044 \times deformation\, percentage) + \ln 6.6 \qquad (2.4)$$

$$and \quad \mu = coefficient\ of\ friction$$

The equation was developed based on the following assumptions:

I. The deformation is accompanied by constancy of volume.
II. Free cylindrical surfaces remain perfectly cylindrical.

III. The deformation is homogeneous, that is, the stresses and strains are uniformly distributed within the material before and after deformation.

IV. The material under deformation is plastic over the entire range of deformation.

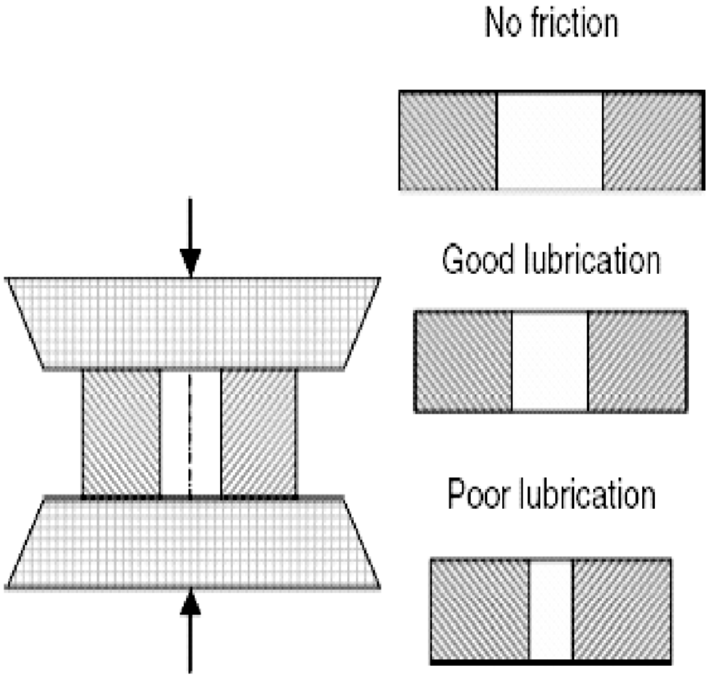

Figure 2.1: Illustration of the Ring Compression Test

Source: Verlinden, *et al.* (2007)

2.8 Previous Work

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 is a well-established method for lubricants evaluation for various processes as well as for the determination of friction coefficient in metal working operations. Another test suggested by Kudo and Kongi and developed by Cockcroft and Male utilizes axial compression of a ring between flat platens (Rowe, 1968). The ring compression test is a very important test in metal forming process analysis. It can be used as a test for flow stress evaluation, and, most widely, it is used as a method for lubricant evaluation (Shen *et al.,* 1992). Hence researchers have over the years used these two methods and others to evaluate lubricants for metalworking operations.

Babaagba (1981) evaluated some locally produced oils (palm, palm kernel, shea butter and groundnut oils) by studying their room temperature performance characteristics based on the average coefficient of friction calculated for each oil using the plane strain compression of circular aluminum blanks.

Oke (1983) investigated the capability of the same oils (palm, palm kernel, shea butter and groundnut oils) in hot-upset forging of commercially pure aluminum rings. He found out that their coefficients of friction were less than those of some standard lubricants in use as obtained by the studies of Bailey and Singer (1963).

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.

Usman (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 than that obtained using the commercial SAE 30 lubricant.

Nyior (1994) investigated the performance of some vegetable oils (palm, groundnut, soya-bean, and shea butter oils) as lubricants for cold extrusion of Aladja ST 60-2 structural steels and found out that they all performed better than the standard zinc phosphate/sodium stearate lubricant at higher reduction speed.

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

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.

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.

Gaminana (2011) evaluated the potentials 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 using the plane-strain compression test. His findings revealed that false walnut oil performed better than the standards used for assessment in both tests. Additionally, he found the three oils assessed suitable for use as lubricants for aluminium cold rolling operations.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1Materials

The major materials used in this research work include: aluminium alloy rings, neem oil, palm kernel oil, and 20W-50 engine oil (used and degraded).

3.1.1 Aluminiumalloy

The aluminium alloy used in this work has the chemical composition shown in table 3.1.

Table 3.1: Composition of the Ring Material (aluminum alloy)

Elements	Al	Si	Mn	Mg	Fe	Cu	Zn	Zr	Ni	Cr	Ti
Amount (%)	99.02	0.158	0.024	0.443	0.292	0.012	0.01	0.02	0.001	0.001	0.004

3.1.2 Oils under investigation

The oils investigated are neem oil, palm kernel oil and 20W-50 motor oil (synthetic and degraded). The neem oil was obtained from National Research Institute for Chemical Technology, Zaria; while the palm kernel oil was purchased from an open market in Minna, Niger state. The fresh formulation 20W-50 motor oil was purchased from a lubricant shop at SabonGari, Zaria, while the degraded one was collected from a vehicle. Table 4.2 shows some physical properties of these oils (the analysis was carried out at NARICT, Zaria-Nigeria).

3.1.3 Equipment

The chemical analysis of the aluminium alloy used was conducted at University of Johannesburg, South Africa using Vegatescan Analyzer. The machining of the aluminium rod into the required dimensions was performed on a Lathe Machine in the Department of Metallurgical and Materials Engineering workshop, Ahmadu Bello University, Zaria, while the ring compression test was carried out on a 500kN Universal Materials Testing Machine in the Strength of Materials laboratory, Department of Mechanical Engineering, Ahmadu Bello University, Zaria. Viscosity measurement of the oils under investigation wascarried out using Synchro-lectric Viscometer in Chemical Engineering laboratory, Ahmadu Bello University, Zaria.

3.1.3.1 Sychro-lectric viscometer

The specifications of this equipment are:

MANUFACTURER: BROOKFIELD ENGINEERING LABORATORIES INC STOUGHTON MASSACHUSETTS
MODEL: RVT
SERIAL: 43329
VOLTS: 230
FREQUENCY: 50

3.1.3.2 Lathe machine

The specifications of this equipment are:

MANUFACTURER: THE COLCHESTER LATHE CO. LTD HYTHE, COLCHESTER, ENGLAND
VOLTS: 415
CYCLES: 50
PHASE: 5

AMPS:	6.7/12
MAIN MOTOR HP:	7.5
PUMP MOTOR HP:	0.05
AUX MOTOR HP:	-
TOTAL HP:	7.5

3.1.3.3 Universal testing machine

The specifications of this machine are:

MANUFACTURER:	DENSION AND SONS LTD HUNSLET FOUNDRY, LEEDS 10, ENGLAND
CAPACITY:	50 TONS
MODEL NUMBER:	T42B2
MACHINE NUMBER:	23313
PAT NUMBER:	571765 551722

3.2 Methods

The total experimental work can be divided into two parts, namely;

1. Sample preparation
2. Compression test

3.2.1 Sample preparation

Blends of each of the two vegetable oils (neem and palm kernel oils) with the degraded motor oil were prepared in the ratios 40:60, 50:50 and 60:40 to produce a total setof three blends for each vegetable oil. Viscosities of these oils in centistokes were measured and the values are presented in table 4.2. The viscosity measurement was carried out at Department of Chemical Engineering, Ahmadu Bello University Zaria.

Aluminum rod of composition as presented in table 3.1 was mounted on Lathe machine and machined to the required dimensions of 48mm outer diameter and 24mm inside diameter. The rod was then cut into 50 pieces of height 18mm each. The surfaces were later polished to give a height of 16mm. The sample dimensions were therefore in the ratio 6:3:2 (i.e., outside diameter: inside diameter: height) which is the dimensional ratio for a standard ring compression sample (Male and Cockroft, 1964-65). To ensure similar surface roughness, the same cutting and preparation techniques were applied to produce all the specimens.

3.2.2 Ring compression test

The test is based on Male and Cockroft ring compression experimental procedure (Male and Cockroft, 1964). Aluminum alloy rings of outside diameter 48mm, inside diameter 24mm, and height 16mm (i.e., ratio O.D: I.D: H = 6:3:2) annealed at 380^0C for one hour were used throughout the experiment. This sample dimension of 48mm x 24mm x 16mm has been used in a previous work by Rao, *et. al.* (2009) in the cold upset forging of Al-4Cu-2Mg alloy, although experiments have shown that larger or smaller specimens would give the same values of the parameter ΔD (i.e. decrease in internal diameter) provided that the geometric similarity was maintained (Male and Cockroft, 1964-65).

Compression was carried out in an accurately-made sub-press, which was mounted on a 500kN Universal Materials Testing machine, moving at a cross-head speed of 4cm/minute.

The dies used for the compression and the aluminum rings were polished to a smooth finish.

The rings were thoroughly cleaned with ethanol to remove dirt and other contaminants from the surface. The surfaces of the dies were also cleaned with ethanol applied by rubbing with a filter paper until the latter remained unstained. This was done after the dies had been lightly rubbed with 600 emery paper to remove any pick up from previous tests. The lubricant under investigation was applied to the surfaces of both the ring and the dies by rubbing with the use of cotton wool. The ring was then placed between the operating surfaces of the dies fitted in the appropriate jig assembly and placed between the compression tables of the 500 kN Universal Material Testing machine.

The required deformation for each lubricant was obtained by means of a dial-gauge arranged vertically on the sub-press in such a way that it was actuated by the descending head of the sub-press at the commencement of compression.

Lubricants investigated for possible friction reduction at the die-workpiece interface are neem oil, palm kernel oil, unused 20W-50 motor oil, degraded 20W-50 motor oil, blends of neem oil and degraded 20W-50 motor oil (in ratios 40:60, 50:50 and 60:40) and blends of palm kernel oil and degraded 20W-50 motor oil (in ratios 40:60, 50:50 and 60:40). For each lubricant investigated, a set of four samples were compressed to give a range of 20 - 50% reductions in height.

Accurate determination of the internal diameter of each of the deformed rings was made by tracing the internal profile of the deformed sample on a piece of paper and retracing the paper trace with a thread. The measured length of the thread was equated to the circumference of the average circle and the diameter was calculated.

CHAPTER FOUR

4.0 RESULTS

4.1 Final Internal Diameter of Rings Obtained Under the Investigated Lubrication Conditions

Final internal diameter of the rings obtained for 20-50% reduction in height under the investigated lubrication conditions are presented in Tables 4.1a-4.1j.

Table 4.1a: Final values for internal diameter of ring with unused 20W-50 engine oil as lubricant

Reduction in height, %	Initial internal diameter of ring, mm	Final internal diameter of ring, mm
20	24.00	23.78
30	24.00	24.10
40	24.00	21.55
50	24.00	22.19

Table 4.1b: Final values for internal diameter of ring with degraded 20W-50 engine oil as lubricant

Reduction in height, %	Initial internal diameter of ring, mm	Final internal diameter of ring, mm
20	24.00	23.78
30	24.00	21.55
40	24.00	21.87
50	24.00	22.82

Table 4.1c: Final values for internal diameter of ring with neem oil as lubricant

Reduction in height, %	Initial internal diameter of ring, mm	Final internal diameter of ring, mm
20	24.00	24.10
30	24.00	23.14
40	24.00	22.19
50	24.00	23.78

Table 4.1d: Final values for internal diameter of ring with palm kernel oil as lubricant

Reduction in height, %	Initial internal diameter of ring, mm	Final internal diameter of ring, mm
20	24.00	24.10
30	24.00	24.10
40	24.00	23.46
50	24.00	23.46

Table 4.1e: Final values for internal diameter of ring with 40/60 neem oil-degraded oil as lubricant

Reduction in height, %	Initial internal diameter of ring, mm	Final internal diameter of ring, mm
20	24.00	23.78
30	24.00	22.82
40	24.00	23.14
50	24.00	24.10

Table 4.1f: Final values for internal diameter of ring with 50/50 neem oil-degraded oil as lubricant

Reduction in height, %	Initial internal diameter of ring, mm	Final internal diameter of ring, mm
20	24.00	24.10
30	24.00	23.46
40	24.00	23.14
50	24.00	23.46

Table 4.1g: Final values for internal diameter of ring with 60/40 neem oil-degraded oil as lubricant

Reduction in height, %	Initial internal diameter of ring, mm	Final internal diameter of ring, mm
20	24.00	24.10
30	24.00	23.78
40	24.00	24.10
50	24.00	22.51

Table 4.1h: Final values for internal diameter of ring with 40/60 palm kernel oil-degraded oil as lubricant

Reduction in height, %	Initial internal diameter of ring, mm	Final internal diameter of ring, mm
20	24.00	23.14
30	24.00	23.46
40	24.00	21.87
50	24.00	22.82

Table 4.1i: Final values for internal diameter of ring with 50/50 palm kernel oil-degraded oil as lubricant

Reduction in height, %	Initial internal diameter of ring, mm	Final internal diameter of ring, mm
20	24.00	23.78
30	24.00	24.42
40	24.00	23.78
50	24.00	23.14

Table 4.1j: Final values for internal diameter of ring with 60/40 palm kernel oil-degraded oil as lubricant

Reduction in height, %	Initial internal diameter of ring, mm	Final internal diameter of ring, mm
20	24.00	23.46
30	24.00	25.05
40	24.00	24.10
50	24.00	23.46

4.2 Physical Properties of Oils Under Investigation

Physical properties of the oils tested for friction reduction are presented in Table 4.2.

Table 4.2: Physical Properties of Oils under Investigation.

Samples	Saponification Value (mg KOHg^{-1})	Iodine Value(mg/g)	%Free Fatty Acid
Pure motor oil	84.00	6.345	1.742
Degraded motor oil	28.00	12.000	4.550
Palm kernel oil	260.00	24.110	5.370
Neem oil	217.39	62.816	5.100

4.3 Viscosities of the Investigated Oils

The viscosities of the investigated oils used as lubricants in centistokes are presented in table 4.2.

Table 4.3: Viscosities of investigated oils in centistokes

Oils	Viscosity (cSt) at 30℃
Neem oil	10.44
Palm kernel oil	8.22
Fresh motor oil	36.23
Degraded motor oil	35.04
40%Neem:60%degraded oil	18.55
50%Neem:50%degraded oil	16.63
60%Neem:40%degraded oil	15.65
40%Palm kernel:60%degraded oil	15.73
50%Palm kernel:50%degraded oil	13.35
60%Palm kernel:40%degraded oil	11.68

CHAPTER FIVE

5.0 DISCUSSION OF RESULTS

5.1 Evaluated Coefficient of Friction for Various Changes in Internal Diameter Obtained Under the Different Lubrication Conditions

Tables 7.1-7.10 in the appendix show the variation of coefficients of friction for the investigated lubrication conditions with percentage reduction.The coefficients of friction, µ, and friction factors, m, were computed using Equations 2.3 and 2.4 respectively. At 20% reduction, pure neem oil, pure palm kernel oil, 50% neem oil:50% degraded oil exhibited the least friction, while 40% palm kernel oil:60% degraded oil had the highest coefficient of friction value of 0.092. As the reduction is increased to 30%, all the oils except unused engine oil, 40% palm kernel oil, 50% palm kernel oil and 60% palm kernel oil demonstrated increased friction. Degraded engine oil has the highest coefficient of friction of 0.142 at this reduction. Its poor performance may be due to contamination and loss of some lubricating properties from previous use. At 40% reduction, degraded oil and all the blends of neem oil with degraded oil exhibited drop in coefficient of fiction values, while other lubricants behaved otherwise. As the reduction was further increased to 50%, all the lubricants, except 60% palm kernel oil:40% degraded oil, 50% palm kernel oil:50% degraded oil and 60% neem oil:40% degraded oil, exhibited drop in coefficient of friction values with 40% neem oil: 60% degraded oil having the lowest value of 0.054.

In the early stages of the reduction (at 20% and 30%) friction was low under unused engine oil and palm kernel oil lubrication conditions relative to neem and degraded engine oils lubrication conditions. Under this low reduction regime, the pressure is not very high, and lubricants can form hydrodynamic film to achieve sufficiently low friction factor. The value of friction factor under this lubrication regime depends upon lubricant viscosity (Wu, 2008). Hydrodynamic lubrication mechanism requires a thick film which can totally isolate die and workpiece surfaces. Fresh motor oil with viscosity of 36.23cSt has a low coefficient of friction in this region. At 30% reduction, blend of 60% palm kernel oil with 40% degraded oil has the lowest coefficient of friction of 0.037, while at 40% reduction, it, together with the blend of 60% neem oil with 40% used oil, has a coefficient of friction of 0.054. At this relatively high reduction of 40%, pure neem oil still has an increased coefficient of friction value. The initial increase in coefficient of friction under pure neem oil lubrication condition is attributable to slow immediate response of its unsaturated fatty acid components (i.e. the oleic and linolenic) to low temperature accompanying low percentage reduction in height since generally increase in temperature usually enhances the rate of reaction as observed previously by Gaminana (2011) for tiger nut oil in plane strain compression test for its potential as lubricant in cold rolling. In essence, any increase in deformation gives rise to increase in temperature which leads to faster reaction rate of fatty acid oils. At 50% reduction in height, the unsaturated fatty acid components of the vegetable oils are active due to increased temperature occasioned by the high amount of deformation and the effect is seen in the drop in their coefficients of friction. Neem oil, having a higher concentration of unsaturated fatty acids than palm kernel oil (as shown in Table 2.2), has lower coefficient of friction of 0.057. Virtually all the blends of each of the vegetable oils with degraded oil demonstrated similar trends with their respective parent vegetable oil with the exception of 60% neem oil and 40% palm kernel oil blends. Poor performance of most of the palm kernel oil blends with degraded oil at higher deformations are attributable to the poor lubricating ability of palm kernel oil as previously reported by Abdulquadir and Adeyemi (2008).

5.2 Percentage Change in Internal Diameter of Rings with Deformation

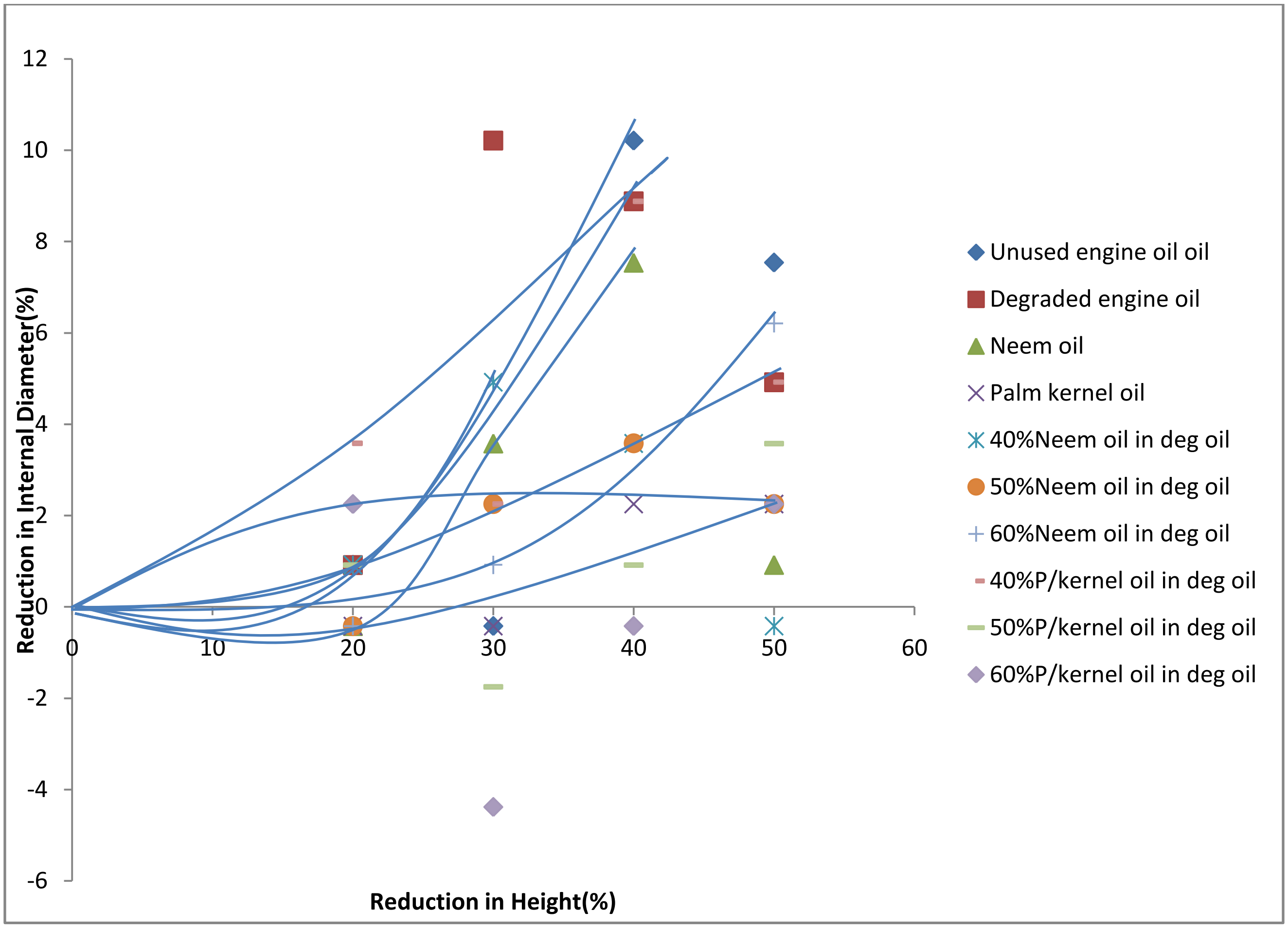

Figure 5.1: Change in Geometry of Standard Aluminum Rings with Reduction in Height for the Various Lubrication Conditions.

Figure 5.1 shows curves of plots of percentage change in internal diameter of the compressed rings, ΔD, with the percentage deformation for the aluminum specimens under the investigated lubrication conditions. The shapes are identical with those obtained by Male and Cockroft (1964-65) for the change in geometry of commercially pure aluminum rings with increasing amounts of deformation at 20°C under various lubrication conditions. The curves plotted are curves of best fit that do not pass through all the points because of the tendency of friction to increase, decrease or remain constant with deformation, as found by Male (1964-65).

By comparing and extrapolating between the present experimental curves at room temperature and standard calibration curves (Male and Cockroft, 1964-65), the average friction coefficients for the lubricants were found to correlate closely with the standards.

5.3 Regression Analysis

Regression analysis is a technique used for modeling and analyzing variables to make a relationship between a dependent and one or more independent variables. It helps one to understand how the value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed. Figures 5.2a to 5.2j areplots of coefficient of friction against percentage reduction in height, and values of R-square obtained from the regression analysis are also shown on plots.

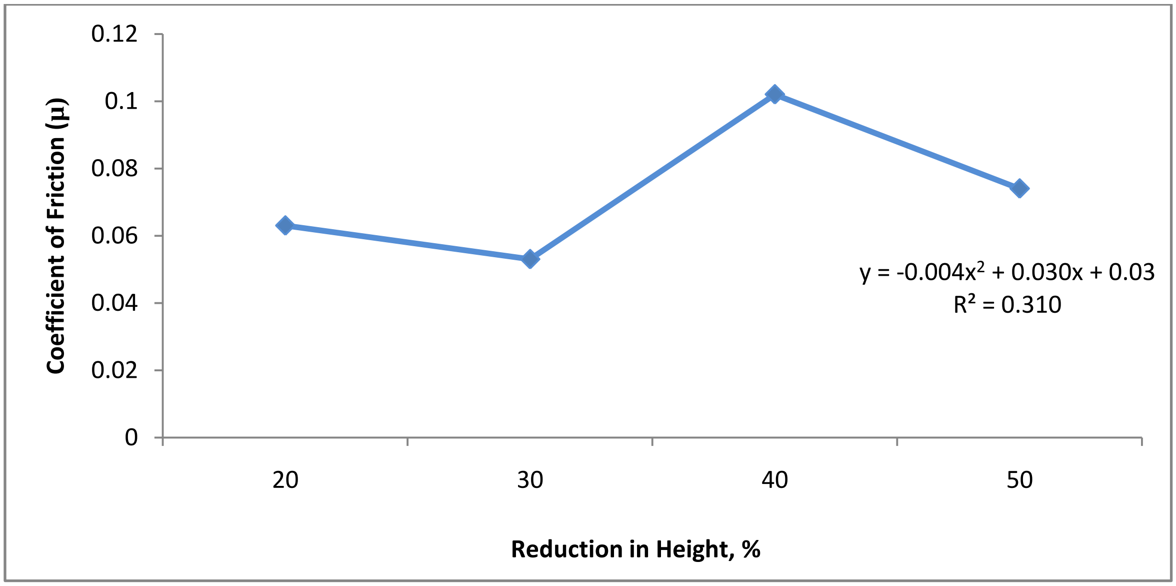

Figure 5.2a: Line Graph for Unused Engine Oil

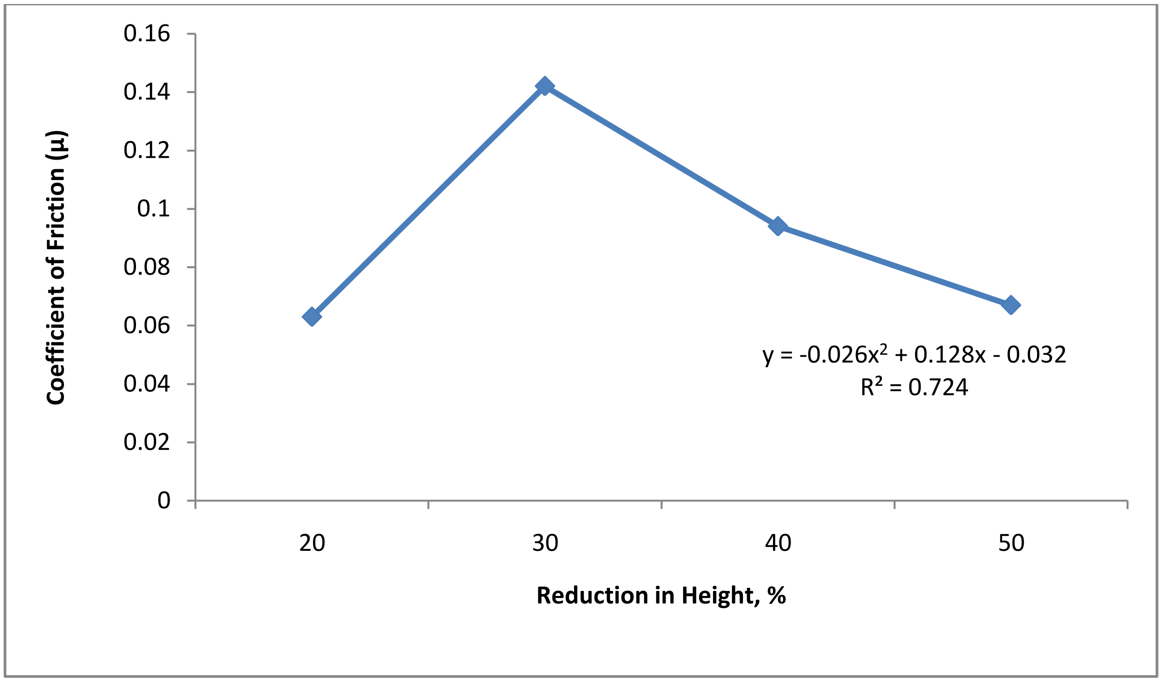

Figure 5.2b: Line Graph for Degraded Engine Oil

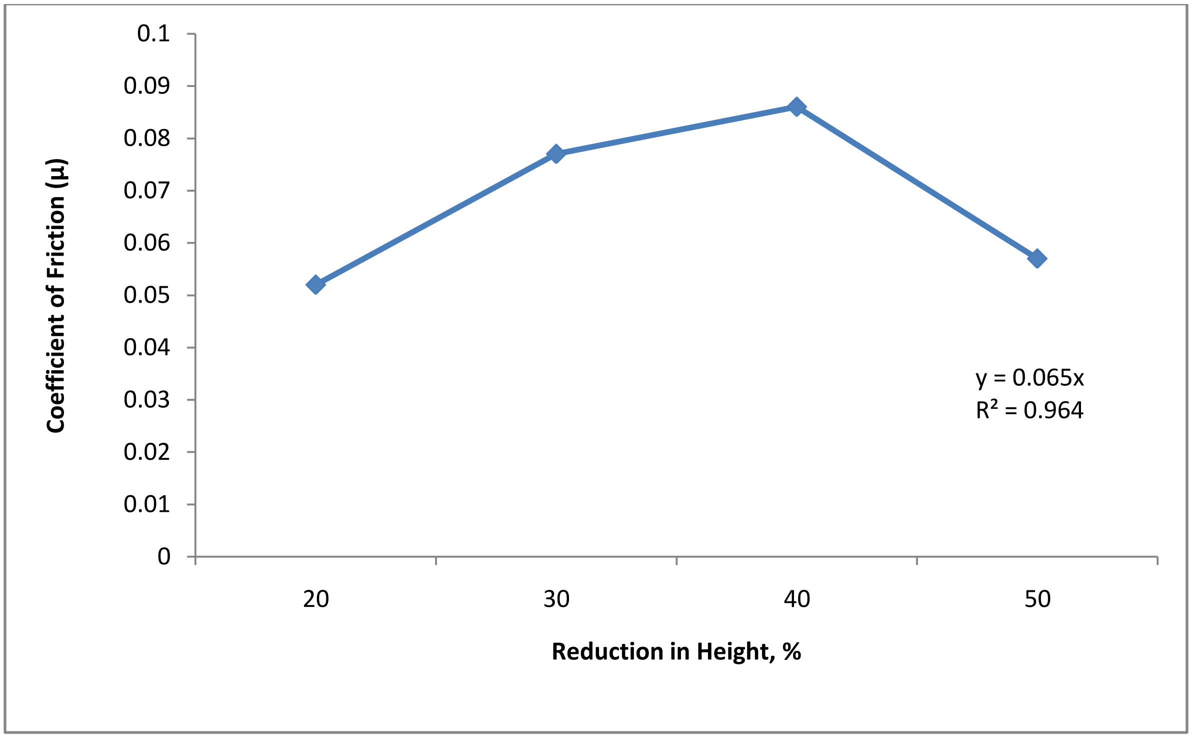

Figure 5.2c: Line Graph for Neem Oil

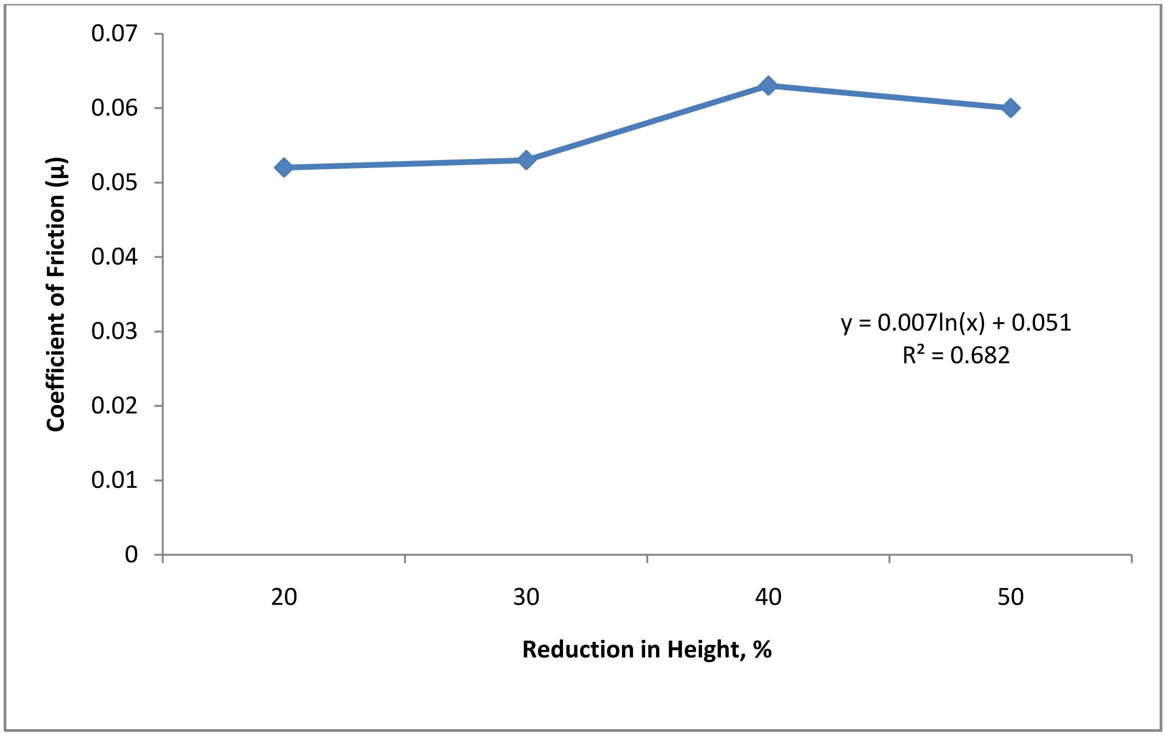

Figure: 5.2d: Line Graph for Palm Kernel Oil

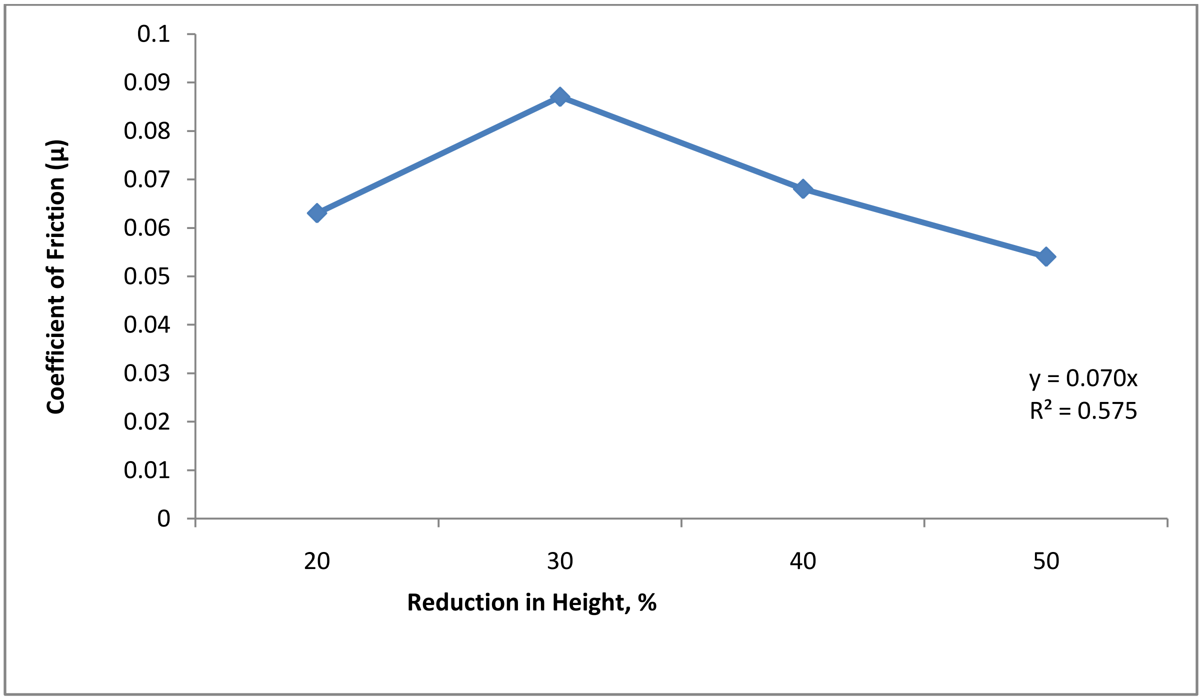

Figure 5.2e: Line Graph for 40/60 Neem oil-degraded oil

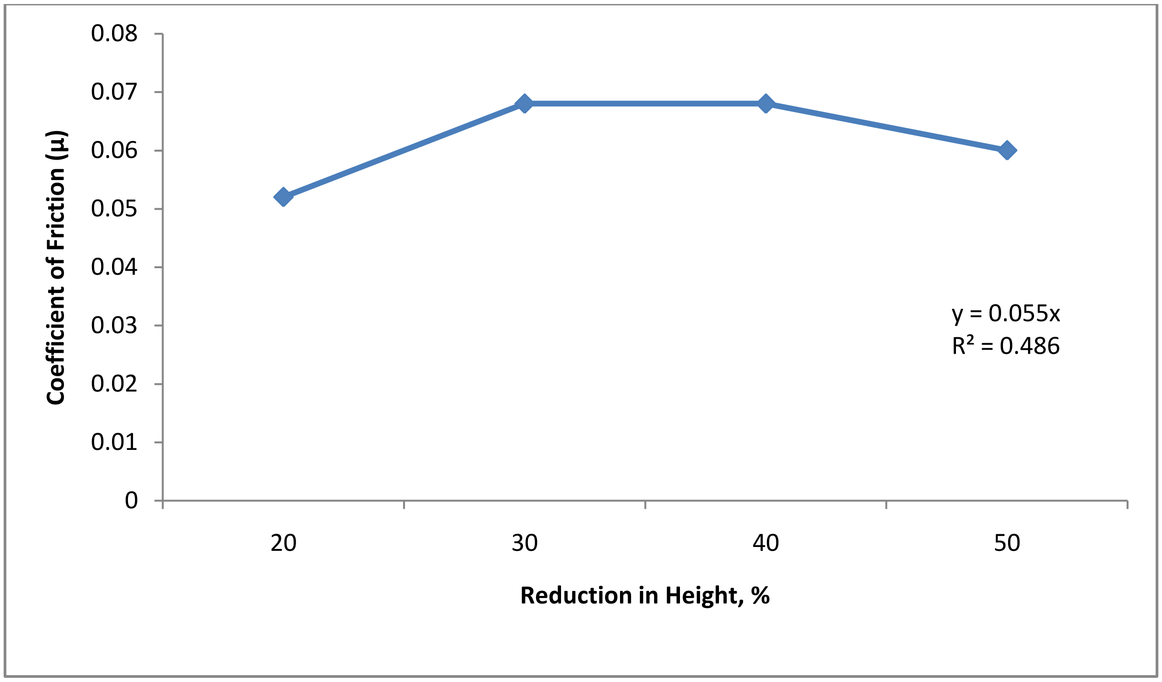

Figure 5.2f: Line Graph for 50/50 Neem oil-degraded oil

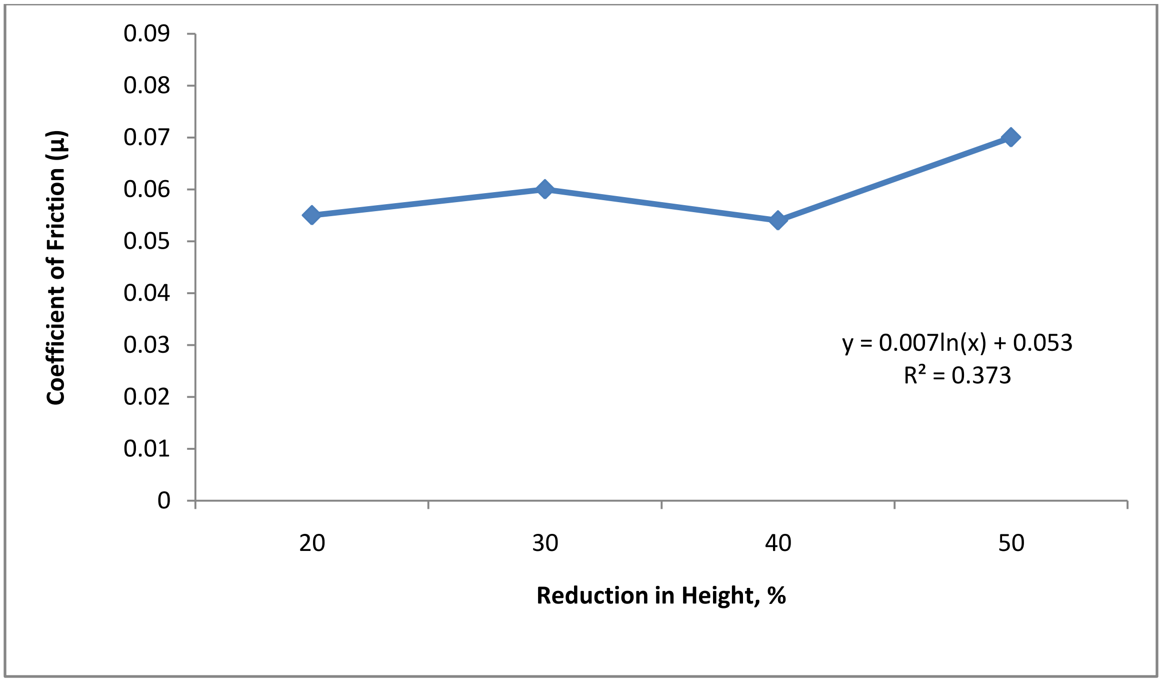

Figure 5.2g: Line Graph for 60/40 Neem oil-degraded oil

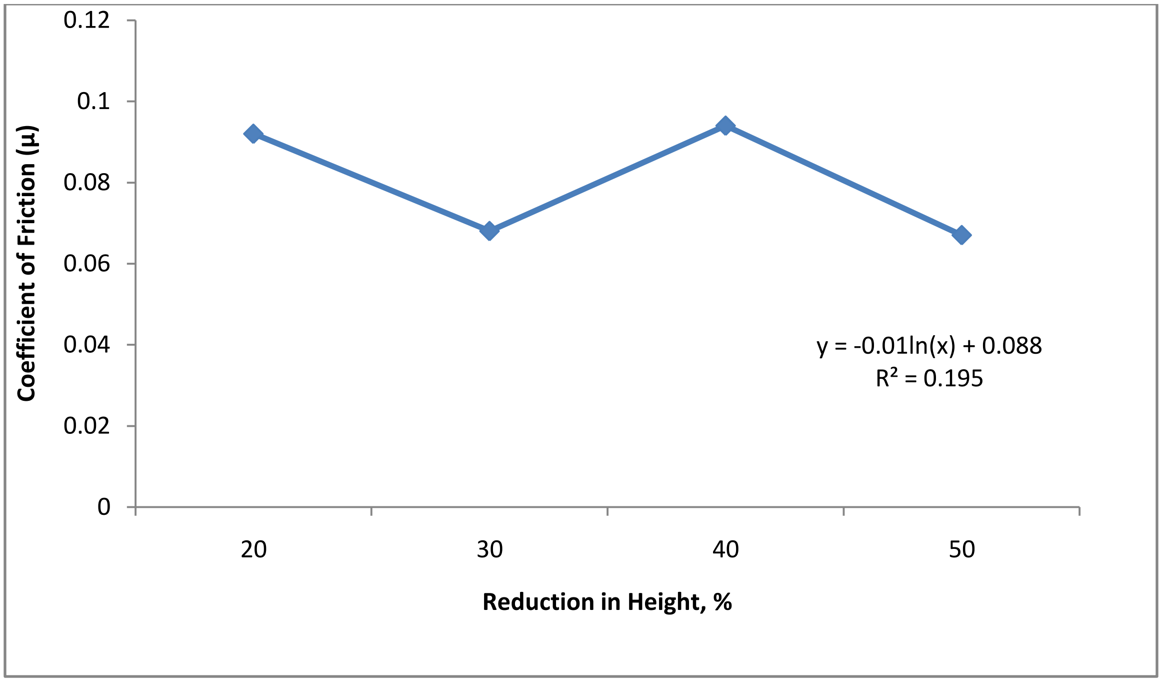

Figure 5.2h: Line Graph for 40/60 Palm kernel oil-degraded oil

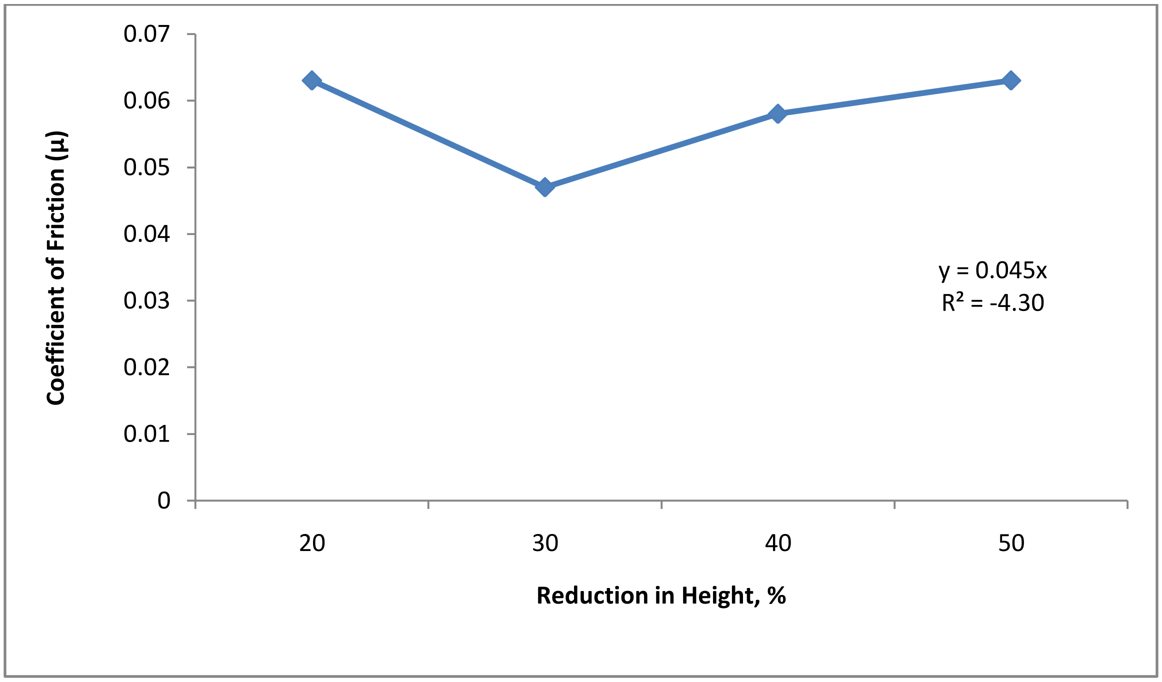

Figure 5.2i: Line Graph for 50/50 Palm kernel oil-degraded oil

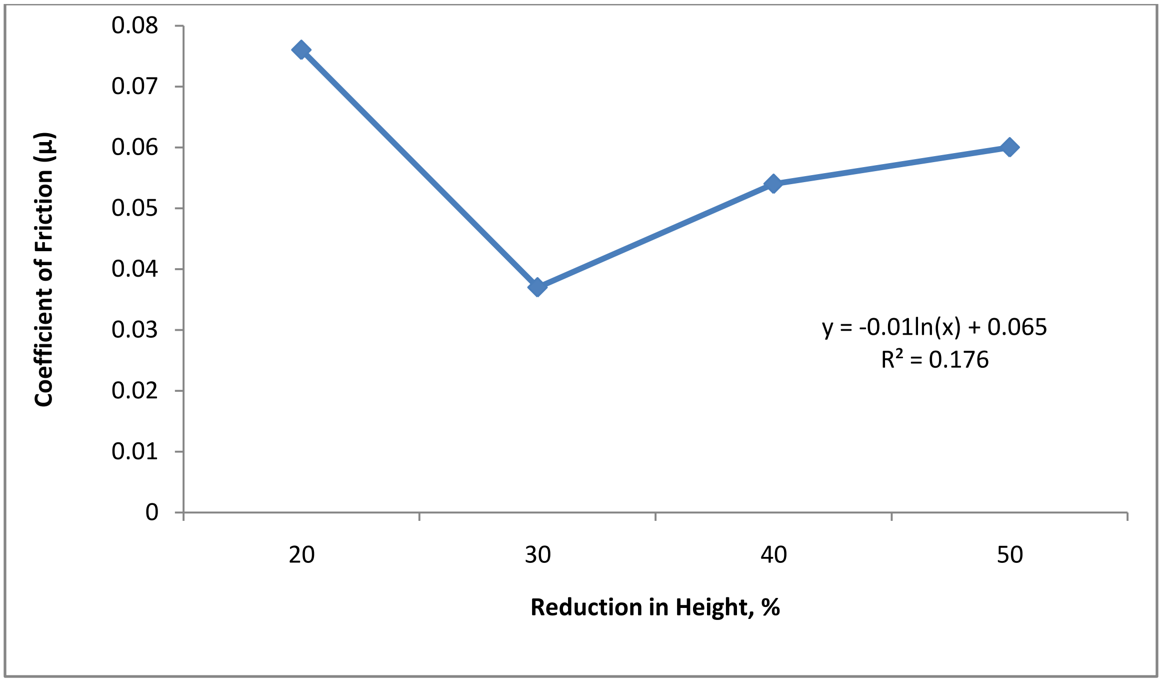

Figure 5.2j: Line Graph for 60/40 Palm kernel oil-degraded oil

Results from the regression analysis revealed that experimental data generated for neem oil is best for prediction purposes. It has the highest R^2value of 0.96 (Figure 5.2c). All the blends considered had R^2 values below 0.5, except 40/60 Neem-degraded engine oil blend with 0.58 (Figure 5.2e).

5.4 Average Coefficients of Friction of the Lubricants Investigated

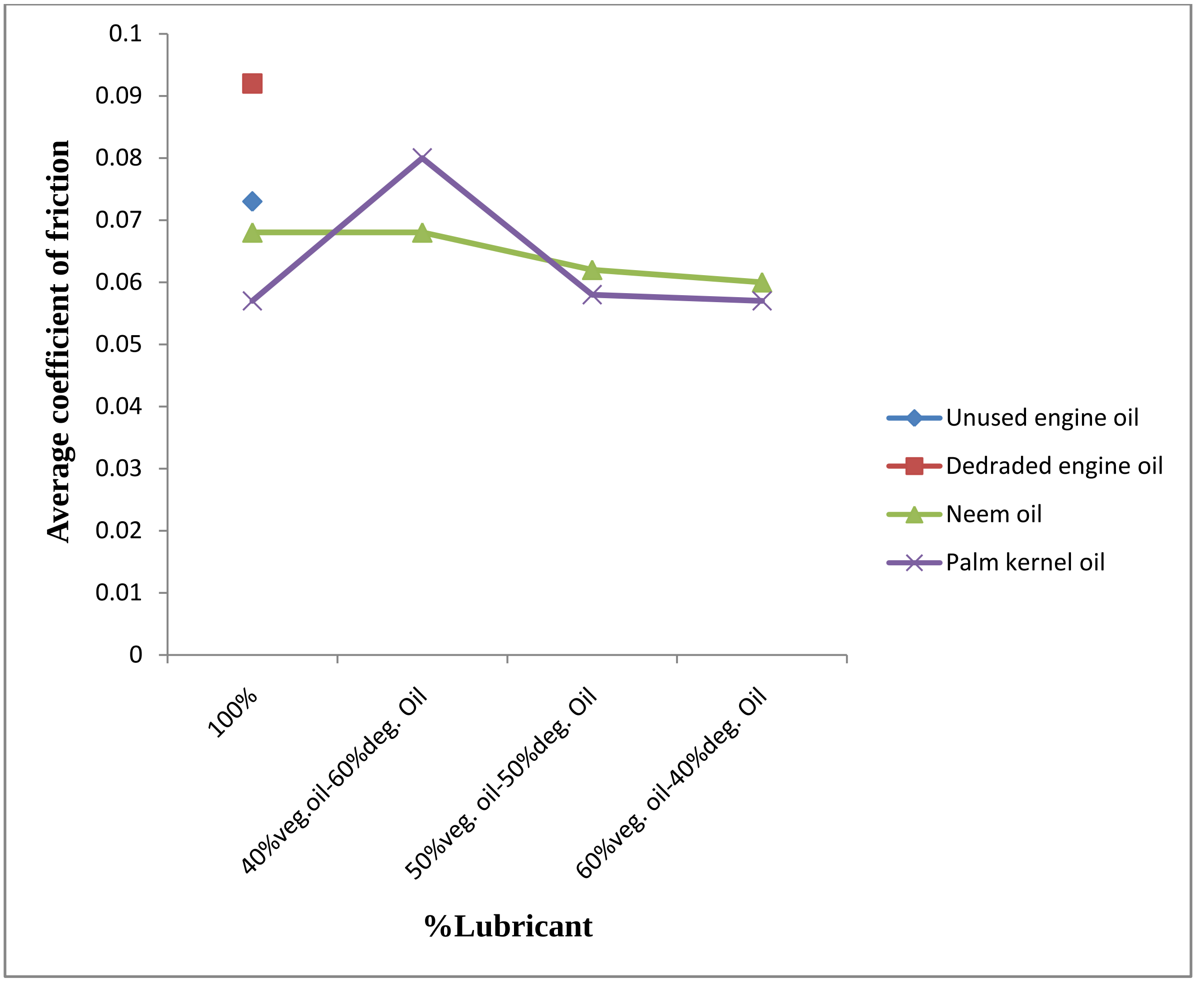

Figure 5.3: Average coefficient of friction for various lubrication conditions

Average coefficients of friction for the various lubrication conditions investigated are presented in a bar graph format as shown in Figure 5.3. For the range of reductions considered, i.e. 20-50%, pure motor oil, degraded motor oil, pure neem oil and pure palm kernel oil lubrication conditions furnished average coefficients of friction of 0.073, 0.092, 0.068 and 0.057 respectively. Average coefficient of friction under degraded motor oil lubrication dropped greatly when the oil was blended with palm kernel and neem oils respectively. With 40% of vegetable oil in the blend, neem oil performed better with an average value of 0.068 against

0.080 for palm kernel oil. For 50% and 60% vegetable oil in the blend, the values for the two oils did not vary appreciably. 50% neem oil furnished 0.062 and 60% neem oil 0.060, while 50% palm kernel oil furnished 0.058 and 60% palm kernel oil 0.057. From the results, it is obvious that 40% neem oil blend with degraded motor oil is twice more effective than the same amount of palm kernel oil in blend with degraded oil in reducing the average coefficient of friction under degraded oil lubrication. However, all the average values obtained for the different lubrication conditions fall within acceptable limits of coefficient of friction for cold forging operation, i.e. 0.05 to 0.1 (Cora, 2004).

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary

Potentials ofneem and palm kernel oils in enhancing friction-reduction properties of degraded motor oil has been investigated using the Male-Cockroft ring compression test procedure. Blends of each of the vegetable oils with the degraded oil in ratios of 40:60, 50:50, 60:40, the unblended vegetable oils (neem and palm kernel oils) and the engine oils (unused and degraded)were used as lubricants for cold upset forging of aluminium alloy rings subjected to percentage deformations of 20, 30, 40 and 50. The test was carried out on a 500kN Universal Testing Machine with cross-head speed set at 4cm/minute throughout the operation. Results from the experiment revealed that vegetable oils such as neem oilhaving favourable physicochemical propertiescan improve friction reduction properties of degraded oilsremarkably.Regression analysis was also carried out and results from the analysis revealed that experimental data generated for neem oil is best for prediction purposes. It has the highest R^2value of 0.96. All the blends considered had R^2 values below 0.5, except 40/60 Neem-degraded engine oil blend with 0.58

6.2 Conclusion

The following conclusions may be drawn from the research conducted:

1. The average coefficient of friction under the investigated lubrication conditions of unused engine oil, degraded engine oil, pure neem oil, 40%neem oil-60%degraded oil, 50%

neem oil-50%degraded oil, 60%neem oil-40% degraded oil, pure palm kernel oil, 40%palm kernel oil-60%degraded oil, 50%palm kernel oil-50%degraded oil and 40%palm kernel oil-60%degraded oil were found to be 0.073, 0.092, 0.068, 0.068, 0.062, 0.060, 0.057, 0.080, 0.058 and 0.057 respectively.

2. Of all the blend ratios considered in this work, 40% neem oil in blend with 60% degraded engine oil (under which average friction coefficient was 0.068) has the most potential of improving lubrication potentials of the degraded oil for cold forging operations since friction coefficient reduces with increasing deformation under its lubrication condition.
3. Palm kernel oil demonstrated weak potentials at improving the degraded oil's friction-reduction properties as the coefficients of friction of most of its blends with degraded oil considered in this work increase with increase in deformation. Although at lower deformation levels they had excellent performance.
4. Vegetable oils having favorable physicochemical properties (such as high iodine value which results in greater chemical reactivity) have better potentials of improving used oils for reuse, as observed for blends of neem oil.
5. All the lubricants investigated have been adjudged suitable for cold forging of aluminum alloys based on the results obtained for average coefficient of friction under their lubrication conditions

6.3 Recommendations

1. Further work may be done on refined degraded oils to study the combined effect of refining and blending with vegetable oils.

2. Wear studies should be carried out to examine the wear-reduction capacity of the oils.

3. Microstructural evaluation of the alloy forged should be carried out to unravel the resultant grain size modification under the lubrication conditions.

4. The test should be carried out under hot working condition to observe the behavior of the oils at higher deformations.

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APPENDIX

Table 7.1: Evaluated coefficient of friction for various changes in internal diameter obtained with unused 20W-50 engine oil as lubricant

Reduction in height, %	Reduction In internal Diameter of ring,% (ΔD)	Friction Factor (m)	Coefficient Of friction (μ)	Average Coefficient Of friction (Σμ/4)
20	0.92	15.912	0.063	0.073
30	-0.42	24.707	0.053	
40	10.21	38.362	0.102	
50	7.54	59.565	0.074	

Table 7.2: Evaluated coefficient of friction for various changes in internal diameter obtained with degraded 20W-50 engine oil as lubricant

Reduction in height, %	Reduction In internal Diameter of ring,% (ΔD)	Friction Factor (m)	Coefficient Of friction (μ)	Average Coefficient Of friction (Σμ/4)
20	0.92	15.912	0.063	0.092
30	10.21	24.707	0.142	
40	8.88	38.362	0.094	
50	4.92	59.565	0.067	

Table 7.3: Evaluated coefficient of friction for various changes in internal diameter obtained with neem oil as lubricant

Reduction in height, %	Reduction In internal Diameter of ring,% (ΔD)	Friction Factor (m)	Coefficient Of friction (μ)	Average Coefficient Of friction (Σμ/4)
20	-0.42	15.912	0.052	0.068
30	3.58	24.707	0.077	
40	7.54	38.362	0.086	
50	0.92	59.565	0.057	

Table 7.4: Evaluated coefficient of friction for various changes in internal diameter obtained with palm kernel oil as lubricant

Reduction in height, %	Reduction In internal Diameter of ring,% (ΔD)	Friction Factor (m)	Coefficient Of friction (μ)	Average Coefficient Of friction (Σμ/4)
20	-0.42	15.912	0.052	0.057
30	-0.42	24.707	0.053	
40	2.25	38.362	0.063	
50	2.25	59.565	0.060	

Table 7.5: Evaluated coefficient of friction for various changes in internal diameter obtained with 40/60 neem oil-degraded oil as lubricant

Reduction in height, %	Reduction In internal Diameter of ring,% (ΔD)	Friction Factor (m)	Coefficient Of friction (μ)	Average Coefficient Of friction (Σμ/4)
20	0.92	15.912	0.063	0.068
30	4.92	24.707	0.087	
40	3.58	38.362	0.068	
50	-0.42	59.565	0.054	

Table 7.6: Evaluated coefficient of friction for various changes in internal diameter obtained with 50/50 neem oil-degraded oil as lubricant

Reduction in height, %	Reduction In internal Diameter of ring,% (ΔD)	Friction Factor (m)	Coefficient Of friction (μ)	Average Coefficient Of friction (Σμ/4)
20	-0.42	15.912	0.052	0.062
30	2.25	24.707	0.068	
40	3.58	38.362	0.068	
50	2.25	59.565	0.060	

Table 7.7: Evaluated coefficient of friction for various changes in internal diameter obtained with 60/40 neem oil-degraded oil as lubricant

Reduction in height, %	Reduction In internal Diameter of ring,% (ΔD)	Friction Factor (m)	Coefficient Of friction (μ)	Average Coefficient Of friction (Σμ/4)
20	-0.42	15.912	0.055	0.060
30	0.92	24.707	0.060	
40	-0.42	38.362	0.054	
50	6.21	59.565	0.070	

Table 7.8: Evaluated coefficient of friction for various changes in internal diameter obtained with 40/60 palm kernel oil-degraded oil as lubricant

Reduction in height, %	Reduction In internal Diameter of ring,% (ΔD)	Friction Factor (m)	Coefficient Of friction (μ)	Average Coefficient Of friction (Σμ/4)
20	3.58	15.912	0.092	0.080
30	2.25	24.707	0.068	
40	8.88	38.362	0.094	
50	4.92	59.565	0.067	

Table 7.9: Evaluated coefficient of friction for various changes in internal diameter obtained with 50/50 palm kernel oil-degraded oil as lubricant

Reduction in height, %	Reduction In internal Diameter of ring,% (ΔD)	Friction Factor (m)	Coefficient Of friction (μ)	Average Coefficient Of friction (Σμ/4)
20	0.92	15.912	0.063	0.058
30	-1.75	24.707	0.047	
40	0.92	38.362	0.058	
50	3.58	59.565	0.063	

Table 7.10: Evaluated coefficient of friction for various changes in internal diameter obtained with 60/40 palm kernel oil-degraded oil as lubricant

Reduction in height, %	Reduction In internal Diameter of ring,% (ΔD)	Friction Factor (m)	Coefficient Of friction (μ)	Average Coefficient Of friction (Σμ/4)
20	2.25	15.912	0.076	0.057
30	-4.38	24.707	0.037	
40	-0.42	38.362	0.054	
50	2.25	59.565	0.060	