TRIBOLOGICAL ANALYSIS OF STEEL AGAINST STEEL CONTACT UNDER EXTREME BY USING DIFFERENT TYPES OF ANTI-WEAR AND FRICTION ADDITIVES

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A report submitted
in fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering (with Honours)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this project report entitled "Tribological Analysis of Steel Against Steel Contact Under Extreme Pressure By Using Different Types of Anti-Wear and Friction Additives" is the result of my own work except as cited in the references

Signature : ....

Name : AMIR SHAHIRAN BIN ABDULL JALIL

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (with Honours)

Signature	:	………………………………..
Name of Supervisor	:	DR MOHD RODY BIN MOHAMAD ZIN
Date	:	……………………………….

DEDICATION

To my beloved mother, Fatimah Bt Ariffin and loving father, Abdull Jalil Bin Ahmad, for their endless support and assurance through all of my journey

ABSTRACT

This study aims to investigate the extreme pressure properties of Alumina (Al_2O_3) nanoparticles as an additive in SAE 15W-40 Diesel Engine Oil to improve the extreme pressure properties of the base oil. Conventional base oil additive failed to provide protective lubrication layer under extreme pressure (EP) and prevent engine seizure. Base oil without nanoparticle also have lower load carrying capability and have high Coefficient of Friction (CoF) and other friction reduction method such as Diamond Like Carbon Coating (DLC) are much more complex and costly. Therefore, low cost and environmentally nanoparticle which is Alumina (Al_2O_3) and Hexagonal Boron Nitride (hBN) are chosen to be used as the extreme pressure additive in diesel engine oil to improve the load carrying capability and reduce the CoF of the base oil itself. The nano-oil are prepared by dispersing hBN and Al_2O_3 nanoparticle with an optimal concentration of 0.5 vol % into the diesel engine oil using sonication method via ultrasonic homogenizer. The tribological test were performed using 4-Ball Tester in accordance of ASTM D 2596 and D 2783 standards. Based on the experimental results, it is found that Al_2O_3 has the potential to improve the extreme pressure properties of the base oil where it reduces the severe adhesive wear and increase the load carrying capability almost twice the load carrying capability of the base oil from 618N to 1236N. Al_2O_3 nanoparticle are also able to reduce the Coefficient of Friction (CoF) up to 48% .These finding are then verified using Scanning Electron Microscope (SEM) and Electron Dispersive X-Ray (EDX) analysis where it is found that Al element are present on the worn surface. Therefore, Al_2O_3 nanoparticles are believed to play three lubricating mechanism which is ball bearing effect, mending effect and tribofilm formation that led to the improvement of the extreme pressure of the base oil. Both nanoparticle plays the same lubricating mechanism however, they display different extreme pressure properties where Al_2O_3 nanoparticles has better extreme pressure properties than hBN nanoparticles as the point of the last non-seizure of Al_2O_3 are higher at 1236N compared to 786N of the hBN nanoparticles. Therefore, the usage of nanoparticle as an extreme pressure additive has significantly improved the load carrying capability and lower coefficient of friction which is significant for the application in modern internal combustion engine.

ABSTRAK

Kajian ini dijalankan untuk menyiasat sifat tekanan ekstrem nanopartikel Alumina (Al2O3) sebagai aditif dalam minyak pelincir enjin diesel SAE 15W-40 untuk memperbaiki sifat tekanan ekstrem minyak asas. Campuran minyak enjin konvensional gagal memberikan perlindungan di bawah tekanan melampau dan mencegah kerosakkan dan kegagalan enjin. Minyak enjin tanpa nanopartikel juga mempunyai keupayaan membawa beban yang lebih rendah dan mempunyai Pekali Geseran yang tinggi (CoF) dan kaedah pengurangan geseran lain seperti salutan karbon seperti berlian (DLC) adalah lebih kompleks dan mahal. Oleh itu,nanopartikel kos rendah dan mesra alam sekitar seperti Alumina (Al_2O_3) dan Boron Nitrida Heksagonal (hBN) dipilih untuk digunakan sebagai aditif tekanan ekstrem dalam minyak enjin diesel untuk meningkatkan keupayaan membawa beban dan mengurangkan pekali geseran minyak asas itu sendiri. Minyak nano disediakan dengan menyebarkan nanopartikel hBN dan Al_2O_3 dengan kepekatan optimum 0.5 vol% ke dalam minyak enjin diesel menggunakan kaedah sonikasi melalui homogenizer ultrasonik. Ujian tribologi dilakukan menggunakan Penguji 4-Bola mengikut piawaian ASTM D 2596 dan D 2783. Berdasarkan keputusan eksperimen,nanopartikel Al_2O_3 didapati mempunyai potensi untuk meningkatkan sifat tekanan melampau minyak enjin di mana ia mengurangkan kehausan yang teruk dan meningkatkan keupayaan membawa beban hampir dua kali ganda keupayaan membawa beban minyak enjin dari 618N ke 1236N. Nanopartikel Al_2O_3 juga mampu mengurangkan pekali geseran sehingga 48%. Penemuan ini kemudiannya disahkan menggunakan analisis Mikroskop Pengimbas Elektron (SEM) dan X-Ray Penyeberan Elektron (EDX) di mana ia didapati bahawa elemen Al hadir pada permukaan geseran. Oleh itu, nanopartikel Al_2O_3 dipercayai memainkan tiga mekanisme pelinciran yang merupakan kesan bebola galas, kesan pembaikan dan pembentukan tribofilm yang membawa kepada peningkatan sifat tekanan ekstrem.Kedua-dua nanopartikel memainkan mekanisma pelincir yang sama namun, mereka memaparkan ciri-ciri tekanan ekstrem yang berlainan di mana nanopartikel Al_2O_3 mempunyai sifat tekanan ekstrem yang lebih baik daripada nanopartikel hBN di mana titik terakhir tanpa kerosakan Al_2O_3 yang lebih tinggi pada 1236N berbanding dengan 786N dari nanopartikel hBN. Oleh itu, penggunaan nanopartikel sebagai aditif tekanan ekstrem meningkatkan keupayaan membawa beban dan pekali geseran yang lebih rendah di mana ia penting bagi aplikasi enjin pembakaran dalaman moden.

ACKNOWLEDGEMENT

I would like to dedicate this study finding and discovery for the future reference of new researcher in Tribology field and Faculty of Mechanical Engineering.

For the unconditional support, advices, and guidance given by Dr Mohd Rody Bin Mohamad Zin, I highly appreciate all he have put in and could not thank him enough. For the motivating comment and review given by my panellist, P.M Dr Fadzli Bin Abdollah and Dr Kamal Bin Mat Yamin which allows me to improve the quality of this study, I dedicated a sense of gratitude and thankfulness. To the technical knowledge and assistance offered by Ms Ayuma and Mdm Hidayah which enabled my experiment and testing to take place smoothly and accordingly, I sincerely thank them both.

To my friend and classmates for their opinion and sharing of information. To all the person that have help directly or indirectly, thank you for your contribution for making this study possible and achievable.

Most of importantly, to our great Almighty God, the owner of knowledge and wisdom for allowing everything to takes places and discovered.

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LIST OF ABBEREVATIONS

Al_2O_3	-	Aluminum Oxide
ASTM	-	American Society for Testing and Materials
API	-	American Petroleum Institute
BSFC	-	Brake Specific Fuel Consumption
COF	-	Coefficient of Friction
DLC	-	Diamond Like Coating
EDX	-	Electron Dispersive X-Ray
hBN	-	hexagonal Boron Nitride
HRC	-	Rockwell C Hardness
ICE	-	Internal Combustion Engine
LWI	-	Load Wear Index
PPE	-	Personal Protective Equipment
SAE	-	Society of Automotive Engineer
SDS	-	Sodium Dodecyl Sulphate
SEM	-	Scanning Electron Microscopy
TAN	-	Total Acid Number
TBN	-	Total Base Number
VI	-	Viscosity Index
WSD	-	Wear Scar Diameter
ZDDP	-	Zinc Dialkyldithiophosphates

LIST OF SYMBOL

μ	-	coefficient of frictiom
f	-	friction force, N
L	-	Length of friction lever arm
P	-	test load , kg
A	-	sum of the corrected load determined for the ten applied loads immediately before weld point
L	-	applied load total load multiplied by lever arm ratio
Dh	-	Hertz scar diameter, mm
X	-	average scar diameter
Dh	-	Hertz diameter of the contact area,
P	-	the static applied load

CHAPTER 1

INTRODUCTION

1.1 Background

Tribology can be defined as the study of two interacting surface which mainly focussing on three principal which is wear, friction and lubrication [1]. Friction and wear are generated when two different surfaces are in direct contact which causes rotational or sliding resistances due to different surface Coefficient of Friction (CoF). The increase in demand of reducing friction and wear has introduce new material to tribology study which is nanomaterial. Nanomaterial have attract numerous industry and researchers to apply nanoparticle as new form of additives especially in lubrication technology based on Dei et al. [2]. The dispersion of nanoparticle into lubricant forms a new type of lubricant known as nanolubricant. Nanolubricant are made of three components which is fully formulated lubricants or base oil, with colloidal solid particles also known as solid lubricant and surfactant [3]. The solid lubricant or nanoparticles serves a special function which is anti-wear or extreme pressure (EP) additives and the surfactant prevents agglomeration of the nanoparticles [4]

As Tribology field evolves, there have been various exciting and successful finding which shows that nanoparticles serve significant improvement in lubricating properties. One of the previous finding states that the addition of spark plasma sintered-Al_2O_3 composites containing barite-type structure sulphates [5] and chromium oxide (CrO) nanoparticle in lubricating oil [6] steadily improve the extreme pressure properties and lower down the CoF that extends the bearing life and susceptible to seizure. The addition of 10nm Nickel nanoparticle in oil with varying concentration of 0.2-0.5% had increased the non-seizure load by 67 %, reduction in wear scar diameter (WSD) by 22% and friction coefficient reduction of 26% compared to the base oil as discovered by Qiu et al. [7]. Therefore, this study is inspired from other finding to analyse the tribological performance of Al_2O_3 and hBN nanoparticles under extreme pressure. Both of this nanoparticles are environmental friendly and low cost making it interesting to be applied into a real application. In this study, 70nm of both nanoparticle are dispersed in SAE 15W-40 mineral diesel engine oil via sonication technique and tribologically tested using 4-Ball Tester. The testing procedure adhere to ASTM D 2596 and D 2783 standards for extreme pressure test under boundary lubrication regime. The improvement in terms of extreme pressure and load carrying capability are then investigated further via SEM and EDX analysis. After such analysis are done, the best nanoparticle to be used as engine oil additive will be chosen which is Al_2O_3 as it shows improvement in extreme pressure properties and reduction in CoF and non-seizure load.

1.2 Problem Statement

With the advancement of material and engine component, lubrication plays a major role in allowing an engine to achieve good Brake Specific Fuel Consumption (BSFC), excellent thermal efficiency, as well as extending the engine life span. Engine oil are demanded to provide protection of metal on metal under EP to reduce wear and prevent catastrophic cases such as engine seizure from occurring where conventional engine oil without nano-additive fail to do so.

The usage of nano-additive are known to be able to improve the important lubrication properties such as Viscosity Index (VI), Total Base Number (TBN), Oxidation resistance and high temperature performance. As the key properties of base oil are improved, the ability of the lubricant to reduce wear rate, CoF, WSD and load carrying capability also improve significantly. Excellent load carrying capability enable seizure to occur at higher load which allows engine to perform exceptionally better even under harsh environment. Furthermore, most research are done only to study the tribological performance of Graphene based additive such as hexagonal Boron Nitride (hBN) or Graphene Oxide rather than Oxide based additive such as Aluminium Oxide (Al_2O_3) under EP.

Therefore, nano-additive is required to be formulated with conventional base oil to improve the tribological performance of the base oil itself. In addition, there is also a need to compare the difference in tribological performance of hBN and Al_2O_3 which both are environmentally friendly and relatively low cost compared to other friction reduction method such as diamond like carbon coating (DLC) which are not available to the normal consumer and any outgoing engine

1.3 Objective

1. To investigate the Extreme Pressure properties of Al_2O_3 nanoparticles as an additive in diesel engine oil
2. To identify the best nanoparticles (alumina and hexagonal boron nitride) in diesel oil engine

1.4 Scope of Project

The scopes of this project are:

1. Only results of WSD against load, SEM and EDX analysis for Al_2O_3 are presented in this report. The results of hBN and base oil against load are obtained from another study conducted by an associate professor from UTeM in his journal titled as "*Effect of hexagonal boron nitride nanoparticles as an additive on the extreme pressure properties of engine oil*"
2. This study uses Al_2O_3 as the nanoparticle to be dispersed in Shell Rimula R4X SAE 15W-40 Mineral Diesel Engine Oil which will then referred as base oil
3. The sample are made by dispersing 0.5 vol % of Al_2O_3 in 150 ml of base oil via sonication using Sartorius Stedim Labsonic P ultrasonic homogenizer for 80 minutes.
4. Tribological test are done using Ducom 4 ball tester under ASTM D 2596 and D 2783 standards
5. The quantitative analysis are done using 3D Non-contact Profilometer to obtain the WSD and wear profile surface.
6. The results obtained are used to compare the tribological performance of hBN and Al_2O_3 nanoparticle in terms of Wear Scar Diameter against Load.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Friction between two rubbing parts is the greatest limitation of ICE both Diesel and Gasoline engine. Lowering friction has become the ultimate goal to enhance both mechanical and fuel efficiency to further extract more output power per fuel mixture burned. In the early days of the ICE being engineered, they are very inefficient and lubrication technology is somehow limited with short drain interval and creates pollutant to the environment. Modern engine could achieve 30-35% efficiency for the fuel combusted where the rest of them are loss in various way. Ahmed Ali et al. found that the major power loss are highest in the engine itself especially in the reciprocating component which is piston ring and the cylinder bore assembly. This is where lubricant plays it role especially nanolubricant with their small molecular size enabling them to squeeze through tight space providing extra protection.

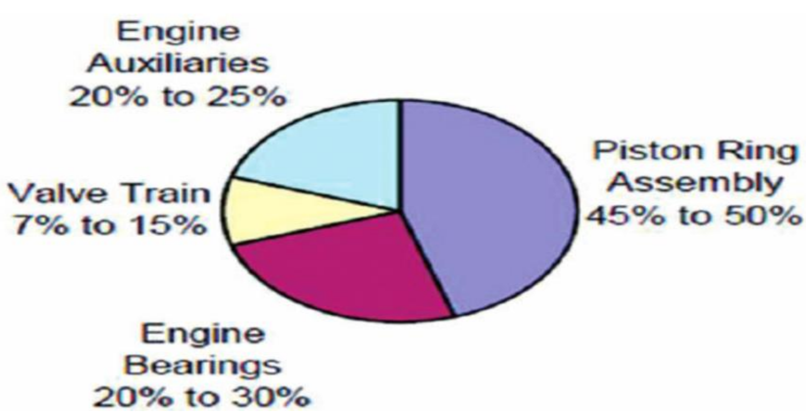

Figure 2.1 : Engine power loss for ICE

[Source : Ahmed Ali et al. [8]]

Lubrication is the key enabling factor to allow an engine to operate in a harsh environment such as extreme temperature, thermal stress and pressure generated from moving and rubbing metal. They work by separating the moving and rubbing metal by forming a protective layer of tribofilm to minimize direct contact and in turn, reduce heat and wear rate. When mentioning about lubrication, we need to observe a Stribeck curve which illustrate the lubrication regime of a lubricant. In Figure 2.2 below, there are three lubrication regime that we need to understand in which the only difference is the thickness of the lubricating film. In boundary lubrication regime, the friction coefficient is the highest since this is where most direct contact of metal occurs. A combination of high load at low rpm worsening the wear and friction which commonly happened during initial start-up of the engine as the oil pump takes some time to feed pressurized oil from the oil sump to all critical parts of engine. Critical engine parts such as crankshaft journal bearing, valve train, and cylinder bore will be the most affected making EP additive the most important aspect to be added in an engine oil. As the pressurized engine oil are supplied by the oil pump, moving components such as journal bearing are floated and the direct contact of metal are now inhibited making the friction coefficient significantly lower as the lubrication regime has shifted from boundary regime to hydrodynamic and elasto-hydrodynamic. Nanolubricant has a significant properties compared to conventional lubricant where they have high viscosity index making them better at maintaining stable film thin film. This enable the critical engine component to work under extreme pressure effectively and the overall engine efficiency can be increased significantly [1].

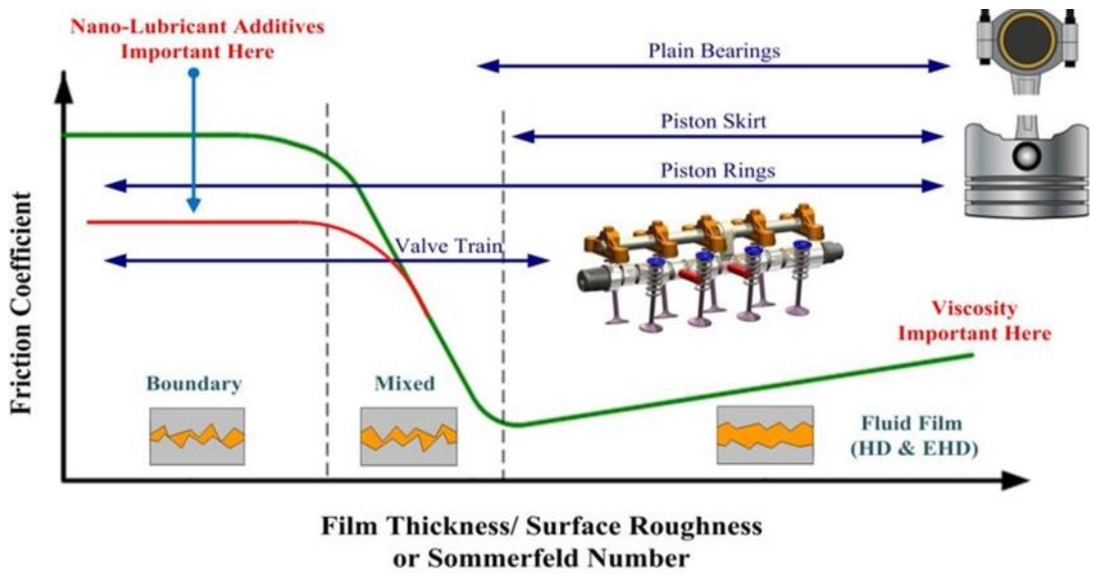

Figure 2.2 : Stribeck curve demonstrating the three different lubrication regime and the nanoparticle role

[Source : Xianjun et al. [9]]

2.2 Nano-Additive as lubricant enhancer

Before nano-additive was discovered, the automotive industry have been relying on macro and microscopic additive to enhance the performance of the base oil back in 1999. Macro and micro additives are found to be inadequate where it cannot reduce friction efficiently since the particle are large in size making them unable to seep through critical area of an engine. One of the most widely used additives is zinc dialkyldithiophosphates (ZDDP) to provide protection against wear where it is found since 1940. ZDDP possess antioxidant properties making it the best in both worlds in terms of reducing wear and as antioxidants. However, ZDDP contain harmful element such as ash, sulphur and phosphorus making it unfriendly to the environment forcing the lubrication industry to seek environmental friendly oil additives with lesser harmful element than ZDDP. This is where nano-additive are discovered and make way into lubrication technology where nano-sized particle with the grain size of 10^9

of a meter are added into the lubricant to control adhesion, friction, stiction and wear at a scale where these nano-sized particles control the outcome [10]. There are five potential advantages of using nano-additives such as (1) insolubility in non-polar base oils, (2) low reactivity with other additives in typical lubricants ,(3) high possibility of film formation on many types of surface (4) higher durability ,(5) high temperature tolerant as mentioned by Spikes et al. [11] . There are a number of effective method to reduce engine friction such as DLC. However, DLC is not readily available and still in research and development phase although few giant manufacturer such as Nissan Motor Company already implement this technologies. As reported by Kano et al., the significance and mechanism of friction reduction mechanism is difficult to studies since the film of the DLC are 1 μm in size and the interactions of DLC with lubricant additives such as ZDDP is not yet establish [12] . In addition, DLC also only been managed to be applied at limited component such as valve lifter, piston rings and valve bucket. Therefore, the usage of nano-additives particle is still relevant considering DLC is not widely available to the current and the previous engine in the market.

2.3 **Optimum concentration of nano-additive**

When dispersing nano-additive, the concentration of the additive is crucial to ensure optimum tribological performance. Too low in concentration would be insufficient and the friction reducing mechanism would be insignificant. Too high in concentration would be excessive and it will effects other additive such detergent and dispersant additive performance. From previous studies, it is reported that the optimal concentration of a nano-oil ranges from 0.1-2.0 % to which proven to provide reduction in CoF and wear rate as reported by other researcher. Mouquan et al. reported that the best concentration of 50 -150nm ALF_3 is 1 wt % when it is added into 100 SN base oil where it exhibits excellent friction reducing and anti-wear properties [10].