AUSTRALIA

University of Southern Queensland

Faculty of Health, Engineering and Sciences

Study on tribological performance of mild steel under canola bio-lubricant conditions

Faculty of Health, Engineering and Sciences

ENG4111 Research Project Part 1 & ENG4112 Research Project Part 2

Final dissertation

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ABSTRACT

The products based on fossil oils are increasing with the concerns of the environmental sectors and academics as well. In this era, there are challenges to find alternative resources replacing the fossil oil for different engineering applications. One of the fossil oil products is lubricant. Fossil lubricants have many industrial applications and involve millions of dollars each year in developments of lubricants due to the huge needs. Accordingly and to satisfy the industrial needs with the environmental considerations, alternative environmental-friendly-Lubricants are nowadays the main aim to identity by the tribologists.

In this project, new lubricants based on vegetable oil were developed. Different blends of canola oil mixed sith fully synthetic two stock engine oils were developed (0, 20%, 40%, 60%, 80%, and 100% of synthetic oil). Viscosity of the prepared blends were determined at different level of temperature (20 ºC – 80 ºC). Tribological experiments were conducted to investigate the influence of the newly developed oil on wear and frictional characteristics of mild steel material subjected to adhesive wear loading against stainless steel. Friction coefficient, weight loss, and specific wear rate of the mild steel were determined under the prepared lubricants' conditions. Scanning electron microscopy was used to examine the worn surface of the mild steel. The results revealed that pure canola oil as lubricant exhibited competitive performance compared to the blend of 80 % synthetic and 20 % canola oils. The viscosity of the canola oil and its blends with synthetic oil is controlled by the environmental temperature since increase the temperature reduces viscosity. Blending the canola oil with synthetic oil increases the viscosity of the lubricants. The experimental results revealed that operating parameters have played the main role in controlling the wear and frictional behaviour of the mild steel since increase the sliding distances increase the weight loss, specific wear rate exhibited steady state after about 5 km sliding distance, and applied loads and velocity showed different influence for different blends. Frictional coefficient of the mils steel was dependant on the applied load and villosity rather than the sliding distance. There was no significances of remarkable the

mixing ratio of canola and syntactic oil since the pure canola oil exhibited competitive wear performance among other blends. However, intermediate mixing ratio (40% - 60% synthetic oil mixed with 60% - 40% canola) can produce slightly low specific wear rate among others.

ACKNOWLEDGEMENT

Through my study in Australia weather in Federation university or in University of Southern Queensland. I would like give my deep thank and appreciation to my supervisor , Associate Professor Dr. Belal Yousif who gave me the opportunity and the support to do this project and taking time out of his busy schedules to lead me in to the right path through Eng 4111 and Eng4112. It was a great pleasure on working with such a project in tribology field. I wouldn't forget to give my deep thank to Mr Mohan Trada (USQ Technical officer) for his help through the experimental procedures and the safety on using the equipment. Also, I would like to give an additional thank to my sweet family and close friends for their support during this journey.

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LIMITATIONS OF USE

CERTIFICATION

I certify that the ideas, designs and experimental work, results, analysis and Conclusions set out in this dissertation are entirely my own efforts, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Faisal H O S R Alajmi

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Signature of Candidate Date

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LIST OF ABBREVIATION

SNO : Synthetic oil

VGO: Vegetable oil

MS : Mild Steel

SWR: specific wear rate

SEM: scaning electron microscopy

FC: Friction Coefficient

SD: Sliding distance

VS : Versus

SYO : Soybean oil

SO : Sunflower oil

CO : Castor oil

USQ: University of Southern Queensland

(EVA) : ethylene–vinyl acetate

(TMP) : trimethylolpropane

(PE) : pentaerythritol ester

(ESBO) : Epoxidized soybean oil

LIST OF UNITS

Cp : centipoise which equals mPas

mPas : mille pascal

N: Newton

Kg : Kilo gram

m/s : meter per second

μ : Friction coefficient

L : Applied load

F_f : Frictional force

ρ : Density

CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

Recently, major concerns have emerged over the increasing use of the conventional fossil fuel in different industrial products and applications. Vegetable oil being an important invention has been the focus of many contemporary researchers in the field of technology and industry. Many studies have been recently done on the possibility of using vegetable oil as a lubricant. The results were promising since vegetable oil showed a lot of potential as being a better alternative both economically and environmentally. There has recently emerged a big controversy on how to involve vegetable oil in the industrial and manufacturing field. The science or the innovation is not in any way limited. The use of vegetable oil has proved beneficial. Recent studies in the fields of technology and engineering have pointed to the possibility of vegetable oil replacing fossils fuels, not just because of the numerous advantages but also since it is environmentally friendly. This is especially important as the world looks to invest more on green energy.

In the contemporary world, Biodiesel has continually received great attention as being an alternative biodegradable and non-toxic renewable source of fuel. Besides, in the industrial world, the attention has further been shifted with the potential use of this invention for lubrication. Initially, petroleum by products was the only ones used for lubrication (Sahoo, 2009). This is however a thing for the past. The emergence of the use of vegetable oil has inspired the extension of this knowledge to the extent that recent discoveries show it being a better alternative for conventional lubricants. Conventional lubricants having their numerous advantages have their share of disadvantages (Dowson, Yaylor & Godet, 2013). The fact that conventional fossil fuel petroleum is in abundance is worth noting. However, this should not bling one to the fact that this fuel is exhaustible (Stachowiak, Batchelor and Stachowiak, 2004). This introduces a new twist in the large scale application of lubricants. Biodiesel, being the better alternative, continues to show unending promise as researchers invest millions of dollars to try and implement biodegradable alternatives.

The application of vegetable oils for lubrication of machinery has been applied for ages. However, much attention shifted the moment cheaper and more available alternatives were found (Stachowiak, Batchelor and Stachowiak, 2004). This attention has since been refocussed due to the continued shrinkage of oil fields. Vegetable lubricants have been majorly motivated by the need to conserve the environment. The next decade is likely to experience the use of biodegradable greases and lubes than it has been in any moment of history.

The balance however tightly hangs in whether this alternative surpasses the conventional lubricants in all aspects. Despite being a renewable source of lubricants and having the advantage in environmental conservation over other sources of lubricants, their demerits cannot be overlooked (Dowson, Yaylor & Godet, 2013). Modification of these lubricants is challenging due to issues having to do with viscosity and alteration of their structure. It is for this reason that researchers have tossed their research into this vast field in trying to improve this source since it shows promise as the next generation group of lubricants in the field of tribology (Wen, S & Huang, 2012).

This work has been motivated by the relevant literature and emerging issues in the field of industry. I aim at focusing on the use of the extensive vegetable oil in available in Australia and its potential use in making lubricants. Nowadays there are many issues with using synthetic oil in the industrial field. Vegetarian oil is very important and alternative oils is the goal of industrial sector and researchers. There are many works have been done recently on the possibility of using vegetarian oil as a lubricant and they found potential work. There are big debates on how to involve vegetarian oil in the industrial and manufacturing field. The science or the innovation has no limit. It is the human been responsibilities to think and try on using something useful and at the same time environmentally friendly.

This work has been motivated because of the literature and the recent issues and I am trying to use available vegetarian oil in Australia as a lubricant for different application. The motivation is what makes me interested in tribology field is firstly, the mechanical motion aspects, Secondly, the availability to involve vegetable oil in to an operation such as in tribology. Thirdly the benefits that is possible to gain and affect positively in the nature. The reducing of petro based lubricant and the increasing of the vegetable oil will reduce the pollution as well as reacting positivily in humanity and animal's health. It is well known that by the years passing the possibility of use a natural alternative for mechanical operation is needed within the increase of the population as well as the increase of the machines that have been used for humanity, an example is (cars, planes, etc.). The selection of vegetable oil was Canola oil due to it is availability and due to its low cost.

1.2 OBJECTIVES

The main objective of this work is to investigate the usage of vegetarian oil canola as lubricant. There are some sub-objectives need to be achieved which are as follow:

1. To prepare canola oil (vegetarian) as a lubricant by mixing it with different blends of fully two strokes synthetic oil,
2. To study the influence of the operating parameters on the wear and frictional behaviour of mild steel materials sliding against stainless steel counterface using the prepared blends,
3. To identify the optimum blend ratio of the vegetable oil with synthetic to gain high tribological performance, and
4. To examine the worn surface of the mild steel characteristics using Scanning Electron Microscopy after the test to show damage features on the surface.

1.3 EXPECTED OUTCOMES

Conducing the experiments on the vegetable oil owing to study its viscosity and influence on mild steel tribological behaviour will significantly contribute to the potential of using such oil in industrial applications. Since the study is initiated at the University of Southern Queensland, this will highly be a very great contribution to the knowledge of tribology and lubricant which can be reported in scientific article. From environmental point of view, there will be reduction in using fossil oil which will contribute to the environment since the prepared oil can substitute the fossil oil in some applications and may assist in several applications in the future.

1.4 ORGANIZATION OF THE REPORT

The report consist of five chapters as introduction, literature review, methodology, results and discussion, conclusion and recommendation. In the literature review, several recent works on the concept of tribology, usage of vegetable oils, and bio lubricants are addressed. Chapter three describes the materials preparation and the way of preparing the blends of the lubricant, experimental setups and experimental procedure. Chapter four represents the results of the experimental works in term of presentation, discussion and arguments. Conclusions and recommendations are introduced in chapter five. The structure of the report showing the organization of the chapter is given in figure 1.1.

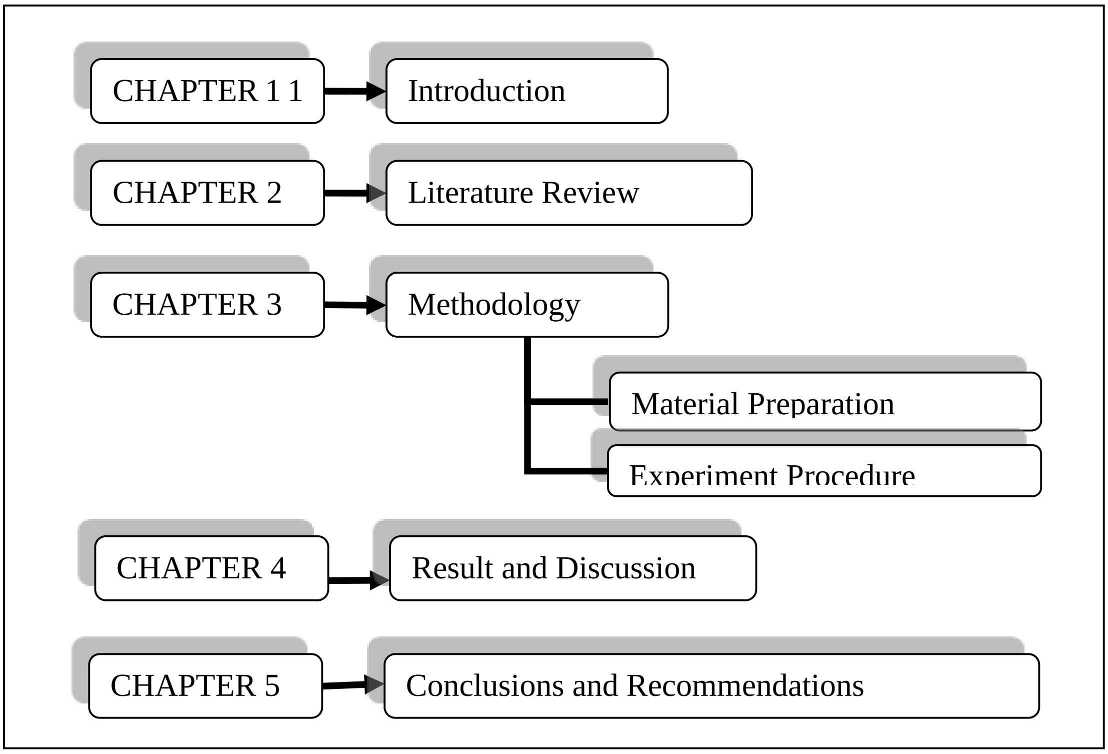

Figure 1. 1 Dissertation lay out showing the chapters and their contents

CHAPTER 2 LITERATURE REVIEW

2.1 HISTORY OF TRIBOLOGY

Science and engineering of interacting surface is known as tribology. Tribology contains the principles of friction, lubrication and wear. This area of technology is closely related to mechanical engineering and materials science as reported by Czichos (2009). When two surfaces are touching each other and have a relative motion between them, there are number of physical phenomena occurs. A friction force can be developed between the surfaces to retard the relative motion between them. During this force development, mechanical energy is converted to other forms such as heat. The surface topography of the material can get altered due to these forces and heat generation. Haessig and Friedland (1991) Stated that the proper analysis and understanding of these interactions and solving the technological problems inherited in these situations comprises the major part of tribology.

In current engineering technologies, especially in mechanical engineering, sliding and rolling surfaces are one of the most important things to study. In designing the machine elements, it is essential to have a good understanding about the tribology principles, (Stachowiak & Batchelor 2013). When two flat looking surfaces are brought in to contact, the surface roughness causes the points of the two surfaces to be contacted at discrete positions and it creates the interfacial adhesion. Then the friction occurs when the two bodies try to move relative to each other, (Williams 1994). Due to these friction forces either surface or both surfaces experience the wear or removal of material. When this happens for a long period of time, the dimensions of the mechanical parts get altered and the machines optimal functionality gets reduced. As an example, in pistons of engines wear out then there can be gas leaks from the places where the dimensions get reduced. This can affect the performance of the engine to a greater extent, (Hirani).

Progress in the philosophical sense is vivid in the field of manufacturing. In the contemporary times engineers focus on reducing both the damage to the environment, energy loss and damage to the frictional components of machines, (de Marchi 1998). Therefore, overcoming friction becomes a very large percentage of many energy consumptions. Tribology has always been present in order for man to achieve his technological needs. This dates back from the use of fats obtained from animals in order to grease chariots and the application of sand for use in lifting heavy loads and blocks used in the building of pyramids in ancient Egypt, (El-Adly & Ismail 2011).

Very few advances are seen having been present from the ancient times to the renaissance period. This was majorly due to the stagnation in civilization in the times described as dark ages. Towards the 15th century, Leonardo da Vinci made major advances and experimented on friction thereby deducing laws of friction. These laws remained buried until the turn of the 17th century when they were unravelled by Amontons, (Carnes 2005). Besides this, the other major mark of tribology in the field of industry was the discovery of oil and the expansion of railways that needed continuous lubrication. From this time, until the 1940s, there was no major change until the time when there was need for better lubrication since wars demanded use of machinery that turned at high speed while having corrosive surfaces. The gas turbine especially, introduced new challenges in the field of industry and tribiology. By the end of 1964, it became clear that the whole concept of lubrication had not been fully explored and there was still much to unravel. The new shortages in the oil industry with worries of oil depletion prompted researchers to direct most of the resources in the field of tribology into finding alternative renewable class of lubricants. The emerging issues with the use of this kind of lubricants are however numerous. There have emerged new concerns over the efficacy and viscosity of this generation of lubricants leading to many resources being channelled towards modification and improvement of this source as the world gears towards biodiesel and alternative lubricants that are both environmentally friendly and renewable, (Nagendramma & Kaul 2012).

Duncan Dowson has in his books surveyed tribology and his application pitting his research and investigations alongside many laws in this field, (Dowson & Dowson 1979). His books and many works comprehensively explore the development and evolution of tribology over the years dating from prehistory, early civilization and eventually developing through the end of the 20^{th} century. Leonardo da Vinci is however credited for having stated two laws of friction, (Reti 1968). It is this that inspired the introduction for a canter of tribology named Leonardo centre for tribology. Leonardo observed that the force that would be needed to overcome friction would double if the weight doubles. However, these finding remained unpublished for a long time.

Even if the name tribology is new the interest in this science has very long history. It is found that the drills made in Palaeolithic period, had bearings made of antlers or bones, (Clark & Thompson 1954). Also, potter's wheel or stones for grinding cereals had bearings to reduce the friction. During 1500s, many developments occurred in the bearing materials. In 1684, Robert Hooke found that the steel shaft and bell-metal bushes are good for wheel bearings. Even though the laws of viscous flow were found by Sir Isaac Newton in 1668, the understating of the lubricated bearing operations did not emerge until the end of the nineteenth century. The study of wear has a shorter history than the friction. Scientific studies of wear developed in the mid-twentieth century, (Blau 2006).

In modern machinery, tribology is a crucial issue. Examples of productive frictions are Brakes, Clutches, Driving wheels, Bolts, Nuts. Examples of productive wear are Pencil, Machining, Polishing, and Shaving. Examples of unproductive wear and frictions are internal combustion engine, Aircraft engine, Gears, Cams, Bearings, and Seals, (Bhushan 2013a).

2.2 Tribology, Manufacturing and Industries

Surface interactions in a tribological interface is highly complex. The understanding of it requires the knowledge in many areas such as, Physics, Chemistry, Applied mathematics, Solid mechanics, Fluid mechanics, Thermodynamics, Heat transfer, Material sciences, Rheology, Lubrication, Machine design, Performance and reliability (Trent 1988).

According to some estimates, losses from neglecting the tribology in United States is about 6 per cent of the gross national product (or $200 billion per year in 1996) . So it is important to study and apply necessary technology in tribology to save the energy and money, (Mansouri & Wong 2005). The savings that can be obtained from proper tribology practices are substantial and significant. The main objective of tribology is to reduce and eliminate the losses resulting from friction and wear from two interacting surfaces. The research in tribology leads to greater plant efficiency, better performance, fewer breakdowns and significant savings. Wear is defined as the removal of materials from one body when subjected to contact and relative motion with another body and there are six fundamental wear modes such as abrasive wear, scratching, adhesive wear, Galling, Scuffing, fretting/fretting corrosion, erosive wear, cavitation, impact, electro-arcing, rolling contact fatigue, spalling, delamination, and tribo-corrosion. When assessing the tribology requirements followings should be considered such as material, coating, lubricant, contact area, surface roughness, sliding speed, sliding mode (unidirectional, reciprocating, multidirectional), duty cycle (Continuous contact, intermittent), environment, atmosphere,(Bahadur 2000).

With the advancement of world economies with many countries pointing towards industrial expansion, the field of tribiology seems as important. There seems to be no way industries will expand without focussing on how friction can be improved. From numerous literature and advanced research in recent times, there have emerged concerns over the huge percentage of energy that goes to friction when dealing with machinery. Industrial advancement means that we should be focussing more on reducing the input while multiplying on the output. This will only be possible if the losses made on friction are explored. Friction not only consumes energy meant for production, it leads to great wear and tear of numerous machine parts leading to numerous losses (Dowson, Yaylor & Godet, 2013).

Tribology in itself has numerous applications. Towards the end of 1990, numerous uses of tribology have emerged. These include green tribology and bio tribology. These areas, being inter-displinary in the technological sense explore wear and tear and lubrication of Nano scale, (Bart, Cavallaro & Gucciardi 2012). The application of tribology, although focussed mainly on bearing design, has recently expanded to include other fields to the extent that it is applied to almost all aspects of technology. In any product that involves moving parts or parts rubbing against each other, there is the involvement of very complex tribological interactions (Bhushan, 2000). Tribology plays a very central role in production and manufacturing. Increased wear and tear means that there will be increased costs for production per unit. This will result in very frequent and unnecessary tool replacement, (Chryssolouris 2013).

2.2.1 Concept of lubricants

One of the effective ways to reduce the friction and wear of two contacting surfaces is to use lubricants in the contacting surfaces. This will provide smooth running conditions for the machine and can extend the life time of the machine to a considerable amount. These lubricant can be liquid, solid or gas. To apply a particular lubricant to a given situation depends on many factors such as, role of surface roughness, mechanism of adhesion, friction and wear, physical interaction between the lubricant and surfaces, and chemical interaction between the lubricant and surfaces. By considering these factors, a suitable lubricant can be chosen for the better performance of the machinery parts.

The roles of the lubricants are Reducing friction, prevent or minimise wear, transporting debris away from interface and provide cooling. The key factors of lubricant effectiveness are Fluid shear properties (Viscosity, viscosity index), Reactivity of the surface, Extreme pressure constituents, Shear strength of solid lubricant or coating and Heat capacity,(Raposo Jr, Oliveira, Neto, Nobrega &Jones 2011).

Due to the development of the proximal probes, especially tip-based microscopies (atomic force microscope and scanning tunnelling microscope) and surface probe apparatus, and other computation technique development, it is easy to study and analyse the surface interactions of two relatively moving surfaces. These microscopes have high resolution hence the structure can be modified or manipulated in nanoscale. These developments pave the path for extensive research in developing the basic understanding of the behaviour of friction and wear in the atomic level and this will allow better design of material properties for mechanical applications. These developments have led to a new technology called micro-nanotribology. This technology allows exploring more in to interfacial processes and I scales from atomic ad molecular to the micro scale. Micro-nanotribology techniques are very important to narrow the gap between engineering and science when it comes to tribology.
The word tribology was reported first in a landmark paper by Jost (1966). The word came from the Greek word "tribo" which has the meaning of rubbing. So the English translation is the science of rubbing. In dictionaries, it is defined as the science and technology of interacting surfaces in relative motion and of related subjects and practices. Tribology is applied in many engineering applications ranging from household appliances to spacecraft.

2.2.2 Petro based lubricants

Petro based lubricants have many similar properties as bio based lubricants but the environmental impact is much more different. Petro based lubricants are commonly used as they are cheap and readily available. Bio based lubricants on the other hand have good physical properties, they are clean and renewable(Ing A, 2009). Petro based lubricants are widely used due to following reasons low cost, readily accessible for the demand, drain interval is long enough.

Even if they have these attractive properties, they are non-renewable and can toxic to the environment. If these lubricants are not properly disposed, they can absorb in to water systems which causes infections or death to many organisms. Some machines used in offshore drilling and in agriculture work closely with the water resources, and using petro based lubricant can be dangerous to the environment. In such situation, bio based lubricants are the only alternative. Bio based lubricants can be derived from either synthetic manner or from animal fats. But the vegetable based bio lubricants have many advantages over the rest. Bio based lubricants have high lubricity, high flash point, viscosity index is stable, clean process and recyclable, non-toxic and degradable.

There are some limitation or disadvantages of usage bio based lubricants such as rapid oxidization, cost is quite high comparing to the petro based lubricant, restricted to be applied in a moderate temperature such as room temperature of 25^{o} and using bio lubricant as an alternative to petro based lubricant surly will affect the food production .

As the public become more conscious about the environment issues, the research on bio lubricants have increased extensively. Chemical process and bio engineering are used to improve the physical properties of bio based lubricants. In some research, additives are used to improve the physical properties of vegetable oils. Vegetable oils rich in Oleic acid such as rapeseed, sunflower and soybean become the most preferred raw material for bio based lubricants production. These oils with high Oleic provides stable lubricants that provides slow oxidization levels.

Conventional soybean contains only 20 percent Oleic acid but the bio engineered ones have a percentage of 83 per cent. In hydraulic pump test, these derived oils have shown 30 times more oxidative stability than the conventional soybean oil. Nutritionally, these soybeans have no difference to conventional soybeans but due to the processing the cost is much higher than the normal soybean(Ing A, 2009). The double Carbon-Carbon bond in the molecular structure of vegetable oils create poor thermal stability and higher oxidization levels. Following techniques are used to saturate vegetable oils such as (transesterification, selective-hydrogenation and selective-hydrogenation via epoxidation).

Annually, epoxidation produce 200000 tonnes of soybean oil. This particular process use Hydrogen Peroxide with the presence of mineral acid to break the Carbon-Carbon double bond in triglyceride and form peroxy acids. The resulting structure is more oxidatively stable but increase the pour point which limit the epoxidized vegetable oils to higher temperature applications. Bio based lubricants have high pour points, which restrict it to be used in low temperature applications. By treating soy bean oil with beached alcohol with a presence of a catalyst, the pour point can be taken down to -15 degrees Celsius. This altered product maintains the viscosity and biodegradability as other oils(Ing A, 2009).

There are three major aspects to be considered which will allow the bio based lubricants to be used as an alternative, it will be applicable in the industry if the cost is low, when offering a sufficient number of land for growing vegetables, if social, physical and political infrastructure applied to support such an idea. Even if the bio based lubricants are costly than the petro based lubricants, it provide energy savings due to high lubricity which can attract the potential buyers. Bio based lubricants lower the coefficient of friction at the pitch point to a greater extent than the petro based oils. The increment of lubricity of bio based lubricants with temperature is higher than that of petro based lubricants. This will allow bio based lubricants to be used in high temperature applications such as injection moulding and heated presses.

2.2 BIO-BASED LUBRICANTS

Researches are carried out to improve the physical properties of bio lubricants which will allow it's used widely in many applications. Bio based lubricants are usually more expensive than petroleum based lubricants. As these lubricants are taken from vegetable oil, care should be taken when deciding the amount to be allocated for lubricant production as this will affect the food production. In current situation, there is no enough land for the production of bio lubricant so the collaboration of government and industry is required in making policies to enhance the production of bio based lubricants (Ing A, 2009). Worldwide consumption of lubricants is around forty million. This ranges from aeroplane engines to office chair. The widely used lubricant type is petro based lubricants. As the oil resources are decaying day by day, soon it will not able to make. Bio based lubricants creates less emission as they have higher boiling point esters. These products are completely free of aromatics and more than 90 per cent bio degradable and non-water polluting. The reduction of oil mist or oil vapour reduces the inhalation of it to reduce health risks. They have good skin compatibility and less dermatological problems with high cleanliness. The polar esters create high wetting tendency which lead to less friction which in turn increase the tool life. Higher viscosity is desirable at high temperature applications. High safety can be obtained as it has high flash point and savings can be obtained from maintenance, man power, storage and disposal cost.

Vegetable oils also reduce the upstream pollution as it derived from plant based rather than extraction and refining pollution done by petro based lubricants. From the point of workers' safety, plant based lubricants are much more safer than petroleum based lubricants as they have low toxicity, high flash point and low volatile organic compound emissions(*Srivatava A, 2013).*

2.2.1 Bio lubricants in industries

Industries and researches are searching for alternative renewable source for lubricants to be used owing to replace the fossil oils. Bio based lubricants are have many properties that give more advantage over the petro based lubricants but they still have some undesirable properties which allow petro based lubricants to be used in many applications. Researches are carried out to improve the quality of physical properties and reduce the cost of using bio based lubricants to compete with the petro based lubricants, (Ramadhas, Jayaraj & Muraleedharan 2004). There are now policies to improve the use of bio based lubricants but still there are some issues with the perception and allocation of land for this purpose. Countries cannot completely change from petro based lubricants to bio based lubricants in a day or two. This must be a gradual process which requires the support from government, agriculture, research and industry. Due to the rapid economic growth in Asia alone, the world demand for lubricants raised to a great extent, (Nagendramma & Kaul 2012). Nagendramma and Kaul (2012) reported that it is predicted that the demand for lubricants will increase 1.6 percent annually for at least another three years from the current demand of 40 million. Even though the consumption is so high, only a small percentage is being recycled. So the need arises to find an alternative which is renewable to compete with the growing need. Bio based lubricants are of limited use and applied in number of environmentally-sensitive industries such as Agricultural machines and other machinery used under or very close to water resources. The reasons for this are Non-toxic, Create a very small disturbance to the echo-system.

Energy saving by use bio lubricants

Here are the approximation energy savings that would be gain through using bio based lubricant in some applications in the industry field such as plastic injection moulding – 2-3 per cent saving, hydraulics – 1-3 per cent saving, Spur gear – 1-5 per cent saving and worm gears – 15-30 per cent saving, (Ing A, 2009). Bio based lubricants can elongate the life of the machine and reduce the maintenance cost as it decreases the coefficient of friction to a greater extent. The initial cost of the lubricant is negligible compared to the savings in energy and maintenance cost. As opposed to biofuels, a specialized crop is needed for quality lubricants which has high Oliec acids, (Governo & Zacharias 2001). Modified soy bean is the only crop that has nutritional quality with high Oliec acids. A hectare of land can produce 446 litres of soybean oil annually but this is only sufficient to lubricate a heavy caterpillar for half a year, (Zappi, Hernandez, Sparks, Horne, Brough, Arora &Motsenbocker 2003).

Following is the table for vegetable oil production for different countries as reported by Shukla and Srivastava (2013)

Table 2. 1 Vegetable oil production for different countries, (Shukla & Srivastava 2013)

Country	Million tons per annum
United States	11
Malaysia	9.6
China	8.9
Indonesia	7.1
India	6.5
Argentina	4.9
Brazil	4.6
Nigeria	1.9
Others	31.7

Base stock comes with number of properties such as high bio degradability, low volatile, ideal cleanliness, high solvency for lubricant additives, miscibility with other types of fluid and negligible effect on seals. The aspects are dependent on the synthetic additives are lubricity, antiware protection, load carrying capacity, corrosion prevention, acidity, ash content, colour, foaming, de-emulsification, water rejection
Hence, when an oil is checked for its suitability for an application, first the base stock properties are evaluated. In addition to that, followings also analysed such as cleanliness, compatibility with minerals, homogeneity during long term storage, water content and acidity, viscosity, viscosity index, pour point, cloud point, cold storage, volatility, oxidative index and elastomers compatibility. There are the four main vegetable oils dominate the industry such as Soybean 31-35 per cent, palm oil 28-30 per cent, rapeseed oil 14-15 per cent and sunflower oil 8-10 per cent

Table 2. 2 Solidification points of different oils, (Yao L,2009).

Name	Solidification point (Celsius)
Palm oil	35 to 42
Palm kernel oil	27
Peanut oil	3
Cottenseed oil	12 to -13
Sesame oil	-4 to -6
Castor oil	-17 to -18
Corn oil	-10 to -20
Rapseed oil	-10
sfflower oil	-13 to -18
Linseed oil	-19 to -27
Soybean oil	-10 to -16
Sunflower oil	-17

2.2.2 limitations of bio lubricants

in developing bio lubricants, the greatest challenge for the researches is to improve the physical properties without harming the biodegradable, tribological and environmental properties. Controlling behaviour consists of following aspects control hydrolytic stability, control of the physicochemical characteristics, control environmental characteristics, control compatibility with materials and seals, control temperature and control oxidative stability, (Agunsoye, Talabi, Awe &Kelechi 2013). Researchers have explored biodiesel tribological issues for close to three decades now. The evaluation, when looked at from a quantitative point of view, the amount of metal gives the various engines a component of wear and tear. The analysis, quantitatively, attempts to give a likely source of these metals. Lubricity issue is very central. With the introduction of low sulphur diesel fuels by regulators in countries such as the United states, has led to the failing of various engine parts such as injectors, (Lin 2013). This is due to the fact that the pumps and injectors are lubricated by the same fuel.

The main challenge of using biodiesel emanates from the concerns over the issue of viscosity when compared to fossil fuels, (Moka, Pande, Rani, Gakhar, Sharma, Rani &Bhaskarwar 2014). Viscosity cannot be altered and any attempts to influence the viscosity of tribological compounds leads to a significant change in the structure and efficacy of these lubricants. These lubricants are delicate in the sense that any little alteration in their structures leads to an effect in the efficacy of these compounds therefore making them less potent and less useful. There have been great obstacles in trying to make the tribological compounds more useful while trying to avoid any alteration in their structure, (Danilov 2015). This has however proved difficult due to the tight balance between conserving both the structure and potency while trying to maintain the usefulness of the product.

2.3 LUBRICANTS BASED ON VEGETARIAN OILS

2.3.1 Debates on vegetable oil

Petroleum is non-renewable natural resource and it is finite. Currently, the resources that produce the petroleum are getting scarce with the development of the industrialization. As a result of this fuel and lubricant prizes will increase rapidly which will impact in an adverse manner to the economy.

On the other hand, plant oils are natural resources which are highly renewable. Recent research has proven that the oils derived from following crops have similar structure to petroleum based oils.

The structural similarity comes from the long chain hydrocarbons which incorporates numerous physical properties to be used as a lubricant. There are concerns about the petroleum based lubricants with regards to the threat to the environment. The vegetarian based oils on the other hand causes minimal threat to human’s health and to the environment.

2.3.2 Considerations in vegetable lubricants

The key properties that should be concerned when selecting a vegetarian oil for lubricant purposes are selected crop should be sustainable , minimal effect on food sources, cost should be economically competitive and environmental and user friendly Research have confirmed that the mesostructured fatty acids in oils derived from plants, as examples, oleic and plasmatic are regarded as the most suitable candidate for lubricants and hydraulic oils (Stymne 2006). Plants that have high concentration of saturated linear fatty acids are not suitable for lubricant applications as they become solid at room temperatures.

Among other types, Oleic acid has become the most desirable mono-saturated acid for lubricant applications. This type of acid can be found in the following crops canola, rapeseed and castor seeds

2.3.3 Vegetable oil advantages

The basic advantages of vegetarian oil against the petroleum based oil are bio mass used to produce bio lubricants are renewable, they can be genetically changed to get good qualities, easily biodegradable, non toxic, low I evaporation loss, prolong the life of the machines due to higher wetting tendency, cost-effective, easy to handle and less maintenance loss

Figure below illustrates the application of bio lubricant in different fields (The Freedonia Group, 2009),

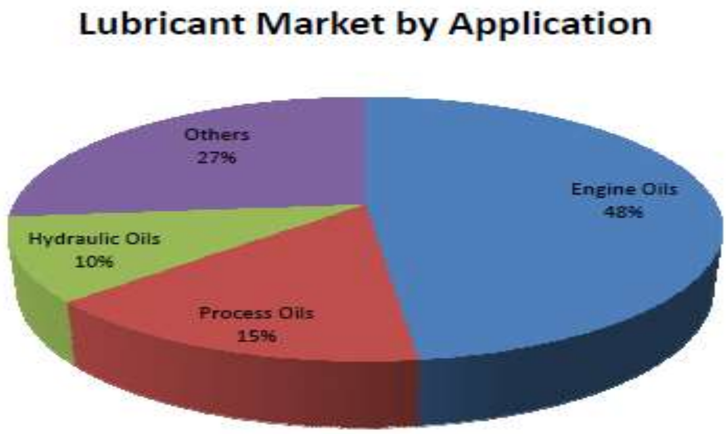

Figure 2. 1 lubricant marks in the recent years

Modern machinery such as engines and tools demands high performance lubricants to decrease the wear and tear. Petroleum based lubricants contains only the base material but bio lubricants have base materials with some additives which can provide many useful properties to the lubricant.

The first step to select a crop for bio lubricant is to study the structure of the plant oil. The composition is mainly dependent on the plant type but following are also have an effect over the structure such as soil type, climatic conditions, season and the mount of sunlight (Fan, 2010).

2.3.4 Fatty acid

Vegetarian oils mainly contain triacylglycerol with other fatty acids. Following table shows the percentages (Fan, 2010),

Table 2. 3 table shows the percentages of fatty acid in vegetable oils, (Fan, 2010)

Chemical compound	Composition / (%)
triacylglycerol	98
Diglycerols	0.5
Sterols	0.3
Free Fatty Acids	0.1
Tocopherols	0.1

The fatty acids on plants contains different acid types such as capric Acid, lauric Acid, myristic acid, plamitic acid, stearic acid, omega 6, omega 3and alpha linolenic. Following table list the composition (percentage) of these acids for saturated fatty acids for different plant types (Fan, 2010).

Table 2. 4 acids for saturated fatty acids for different plant types (Fan, 2010).

Plant oil	Capric Acid	Lauric acid	Myristic Acid	Palmitic Acid	Stearic Acid
Corn	-	-	-	11	2
Soy bean	-	-	10	5	21
Castor bean	-	2.4	2.4	2.4	2.4
New Rapeseed	-	-	0.5	4	1
Palm Kernel	-	50	15	7	2
Sunflower	-	-	-	6	4
Linseed	-	-	-	10	5

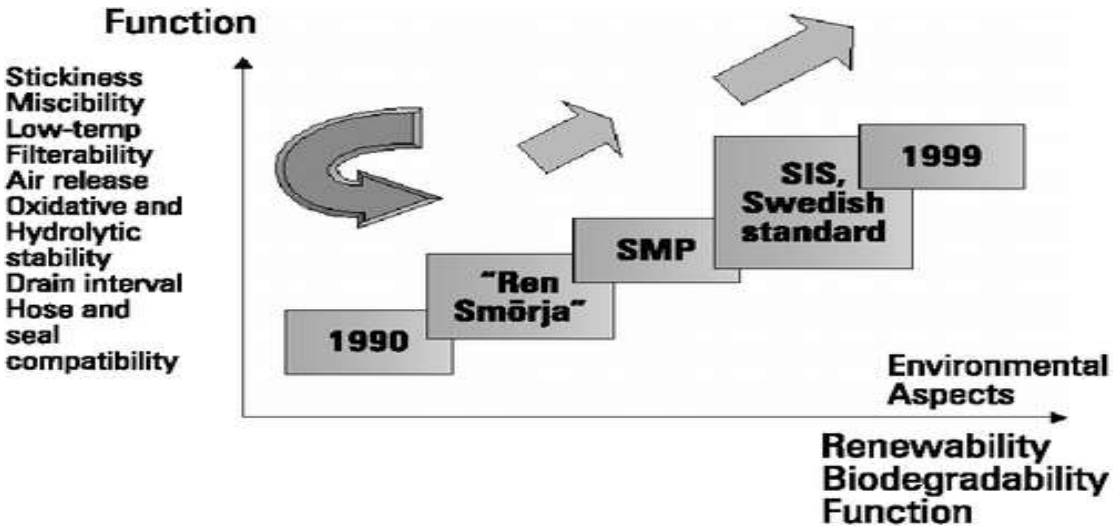

Figure 2. 2 Importance of the bio oil in terms of applications and renewability (Norrby & Kopp 2000)

Following table list the composition (percentage) of these acids for unsaturated fatty acids for different plant types (Fan, 2010),

Table 2. 5 list the composition (percentage) of these acids for unsaturated fatty acids for different plant types , (Fan, 2010)

Plant oil	Oleic Acid	Ricinolenic Acid	Linoleic Acid	Alpha Linolenic Acid
Corn	28	1	58	1
Soy bean	53	0.5	8	0.5
Castor bean	7.4	87	3.1	-
New Rapeseed	60	9	20	9
Palm Kernel	15	-	1	-
Sunflower	28	-	61	-
Linseed	21	8	53	8

2.4 CANOLA OIL AS LUBRICANT

Vegetable oil types are many. Canola oil is one of most important type of oil. Canola oil is available around the world it is price is low and reasonable. Now in Canada Canola oil is third most important product(Rowe, Shesjey & Owen 2005). Canola oil can be possibly blended with different oil which make it one of the best choice. Canola oil is rich of oleic and linolenic acids which lead to a healthier life.

Canola oil is extracted from the seeds of canola plant. Canola plant was developed from rapeseed oil plant by plant breeders since rapeseed oil plant had limitations to human and animal consumption, (Day 2013). Rapeseed oil contains a large percentage of erucic acid. Erucic acid is not good for human consumption. Animal meal produced from rapeseed oil has been found to contain large content of glucosinolates which have been found to suppress animal growth rates when consumed in high doses. It is for these reasons that plant breeders embarked on the development of rapeseed plant varieties with low content of erucic acid; low-erucic acid rapeseed (LEAR) and also low on glucosinolate content, (Aachary, Thiyam-Hollander & Eskin 2014). In Canada, rapeseed plant breeders named LEAR canola for the purposes of marketing. With low levels of erucic acid, glucosinolate, and saturated fats, LEAR (canola oil) appealed to consumers conscious with their health and this increased its demand. The production of canola oil has increased dramatically since World War II.

In industrials, Canola oil is also used for the production of biodiesel, a form of biofuel used to run automotive engines. Besides being used to produce biodiesel, (Bassam 2013), canola oil has been also used to produce a variety of consumer and industrial products such as lubricants because of its non-toxicity,(Mobarak, Mohamad, Masjuki, Kalam, Al Mahmud, Habibullah &Ashraful 2014). The content of the triacylglycerol in plants varies with the plant type. As an example, yellow mustard contain triacylglycerol about 27% and brown mustard contains 36% of triacylglycerol (Fan, 2010).

Table 2. 6 The table below list the triacylglycerol percentage for different plant types(Fan, 2010)

Plant	Percentage
Corn	7
Soy bean	20
Canola	40
Safflower	40
Mustard	40
Castor	45
Flaxseed	45
Peanut	50
Palm Kernel	50
Sunflower	55

CHAPTER 3 METHODOLOGY

3.1 INTRODUCTION

In this chapter, the preparation of the oil and the experiments will be addressed. Different blends of vegetable oil combined with fully synthetic oil are prepared. The experiments were conducted using a newly developed machine at USQ by a previous PhD student. These experiments aim at exploring the basic mechanism through which the tribological compounds are extracted and in great detail on how they achieve their lubrication effect. The experiments further seek to highlight the differences in both the viscosity of the compounds and how these differences are used to explore the probability of using triboilogical compounds for lubrication on the large scale. These experiments provide a model through which we can exploit the use of these compounds in the field of industry and research. In brief, are the explanations on how the various principles have been explored and simplified for a smaller model.

3.2 MATERIALS PREPARATION

The vegetable oil used in this work is obtained from the super marked as marked as vegetable oil. The specification of the oil is presented in appendix B. to prepare the blends of the lubricants, the vegetable oil should be heated up to 50 ^{o}C. at this temperature, the synthetic oil can be poured carefully to the vegetable oil. Electrical mixer at very low speed is used to get uniform mixture. The blends kept for a week to ensure the homoginousity of the mixture. If there is separation in the oil, the blend should be despised. Since, Alotaibi 2014 suggest the usage of such oil in two strokes engine oils, in the current study, fully synthetic catrol oil for two stroke engines is used as synthetic oil. By blending fully synthetic oil 2 stroke engine with vegetarian oil. The blend made up in different quantity 20% synthetic, 40% synthetic, 60% synthetic and 80% synthetic mixed with rest of percentage of vegetable oil. After Apply heat up to 50 degree to make the blends well mixed. Blends figure shown below.

Figure 3. 1 Prepared blends of lubricants.

The specification of the selected canola oil given in Table 3.1. Values of different parameters for canola oil is included and presented below and the specifications of the selected fully synthetic oil is given in Table 3.2.

Table 3. 1 Canola oil Specification (Przybylski, Mag, Eskin &McDonald 2005)

Parameter	Value
Relative Density (g/cm3; 20°C/water at 20°C)	0.914 - 0.917
Refractive Index (nD 40°C)	1.465 - 1.467
Crismer Value	67 - 70
Viscosity (Kinematic at 20°C, mm2/sec)	78.2
Cold Test (15 Hrs at 4°C)	Passed
Smoke Point (°C)	220 - 230
Flash Point, Open cup (°C)	275 - 290
Specific Heat (J/g at 20°C)	1.910 - 1.916
Thermal Conductivity (W/m°K)	0.179 - 0.188

Table 3. 2 Fully Synthetic oil specification (Moses & Roets 2009)

Colour	DEEP RED
Density at 15°C, kg/L	0.895
Viscosity,Kinematic,cSt at40°C at 100°C	 39 7.8
Viscosity Index	175
Biodegradability, OECD 301B, %	64
Flash Point	94
Sulphated Ash, Mass %	<0.10
Base Number	2.5

3.3 TRIBOLOGY MACHINE

Here is a graph show the parts of tribology machine shown below plus is part components. Principles of tribology mainly consists of wear, friction and Tribology lubrication. Designing of the tribology machine has been made and fabricated locally at university of southern Queensland. Listing of Tribology machine components and figure provide below in Fig3.2. The most important part of Tribology machine is the rotational counterface that has been made of stainless steel, a container that is going to be fill by the different blends, an arm that is connected to the container which supplies the load in to the samples. The sample that the test would be apply on is mild steel. At This project, environmental temperature will be considered only in the experimental work. Sliding speed of (0-2m/s) and a sliding distances (0-10km) will be used in the experiments.

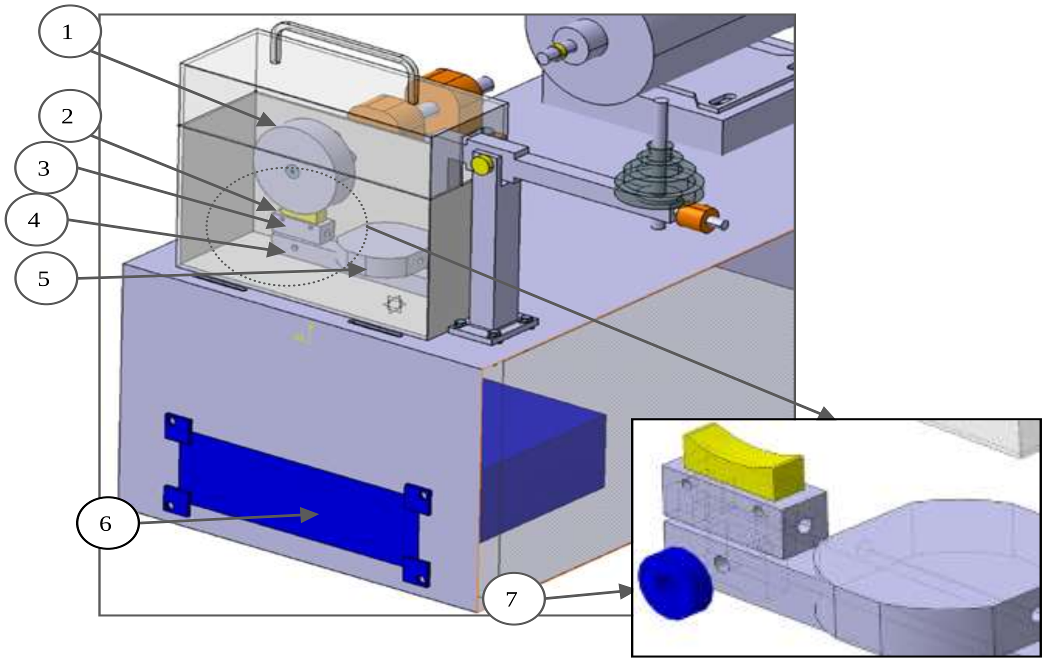

Figure 3. 2 Tribology machine and its components

1 counterface, 2 sample, 3 Sample holder, 4 Lever, 5 Load cell, 6 Power supply unit, 7 Ball bearing

3.4 EXPERIMENTAL PROCEDURE

Samples should be prepared and intimate contact between the samples of the counterface should be ensued. The samples were rubbed with smooth sand paper with grade of 1500 G. this is also repeated with regard of the counterface before each test to ensure the same conditions. Before operating the machine, samples were cleaned, dried, and then weighted. The sample then fixed on the holder of the machine, the timer set to zero, and the load cell reader also set to zero. The machine then operated to the required distance at the required load. After the test completed, debris can be collected, the samples cleaned, dried and then weight. The different in the weight of the samples are determined. Frictional forces are captured during the experiments and plotted against the sliding distance. The tirbology machine as you can clearly see at the bottom left used in the study is available at USQ which has been designed and fabricated by USQ PhD candidate .Tribology machine consist of the shown parts, mainly are the holder No 3 to carry the sample No 2 which in contact with the counterface of No 1. The interface force between the counterface and the sample was measured using the load cell No 5 which is integrated with data system into a computer.

3.4.1 Viscosity measurement

The viscosity of the prepared blends was measured using a Viscometer at the University of Southern Queensland, Figure 3.3. Different oil temperatures were considered (10 ^{o}C - 80 ^{o}C). The oil fist put in a small container and then placed in the machine. The temperature set to the maximum and then the viscosity vs. the temperature is recorded.

Figure 3. 3 Visco-meter at university of southern Queensland.

Scanning Electron Microscopy was used to examine the worn surfaces of the mild steel samples. Scanning electron microscope, machine at the University of Southern

Queensland is branded as Joel, desktop machine. There are different facilities which can be used with this machine to categorize the wear mechanisms.

Friction coefficient μ can be found by using equation (3.1) where L is the applied load and F_f is the frictional force that is captured via the load cell.

$$\mu = \frac{Ff}{L} \tag{3.1}$$

Equations for specific wear rate

Calculating specific wear rate *(SWR)* of the mild metals can be obtained by using equation (3.2):

$$SWR = \frac{\Delta w/\rho}{L \times D} \tag{3.2}$$

Weight loss can be calculated by using equation (3.3) that by weighting the samples of mild steel before and after testing.

$$\Delta \text{Weight} = \text{Weight(before)} - \text{Weight(after)} \tag{3.3}$$

CHAPTER 4 RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter the results of the viscosity in different temperature, friction on the operation tribology machine, wear result data from tribological application and surface characteristics of mild steel that has been tested with different blends and application will be addressed. Discussion in each parameters and their effect on these aspects such as surface of mild steel, wear and friction.

4.2 VISCOSITIES OF THE BLENDS

Here is the result was found by using Viscometer. The results as shown below as a graph and the relation between temperature and viscosity. Viscosity of the prepared blinds at different temperature are presented in figure 4.1. The figure clearly shows that the increase in the temperature decreases the viscosity of all the blinds. This is a typical nature of the lubricant behaviour, since the shear forces reduces with the increase of the temperature which led to low viscosity. To show the comparison among different blinds, the bar chart of show the value of the viscosity with of the pure vegetable oils with different percentage of synthetic oils. The charts shows that the increase on the percentage of the synthetic increases the viscosity. It seems the addition of the synthetic and due to the presence of the lubricant additives in stabilise and increase the viscosity of the prepared blend. Since there is no much time to get the right explanation, this can be added in the recommendation and future work.

Here is a table show up the relation between Temperature in C° and Viscosity in Cp≈ mPa for four blends after apply heat from 10° up to 80°. The test has been used through Viscometer. The process was very long and a bit complicated. Controlling the temperature was main challenge I have met through the test, especially when dropping the temperate down to 10° C. The viscosity of the blends has been test by 25˚ C due to room temperature.

The increase in the viscosity with the addition of the synthetic to the vegetable oil may be due to the synthetic additives in to the vegetable oil which plays the main role in controlling the viscosity as shown in Figure 4.2. This has been evidence in reported works by (Alotaibi.J, 2014). In that work, the vegetable oil better performance with the addition of the synthetic oil and there were increase in the viscosity that leads to minimise the friction and improve the wear in the operations that are done by the tribology machine.

Table 4. 1 Viscosity results for different percentage blend in different temperature.

Temperature	20% SNO +80%VGO	40% SNO +60%VGO	60%SNO +40%VGO	80%SNO+ 20%VGO
10˚ C	156 mPas	170 mPas	177.4 mPas	185.2 mPas
20˚ C	111 mPa	121 mPa	132.9 mPas	145.5 mPa
25˚ C	85 mPas	92 mPas	106.6 mPas	120.4 mPas
30˚ C	72 mPas	81.5 mPas	87.3 mPas	96 mPas
40˚ C	52.5mPas	56.8 mPas	60.9 mPas	65 mPas
50˚ C	36.6mPas	40.6 mPas	44.6 mPas	49 mPas
60˚ C	28 mPas	30.5 mPas	32.7 mPas	37.8 mPas
70˚ C	20.7 mPas	23.8 mPas	27.6 mPas	30.6 mPas
80˚ C	14.8 mPas	17.6 mPas	20.5 mPas	23.8 mPas

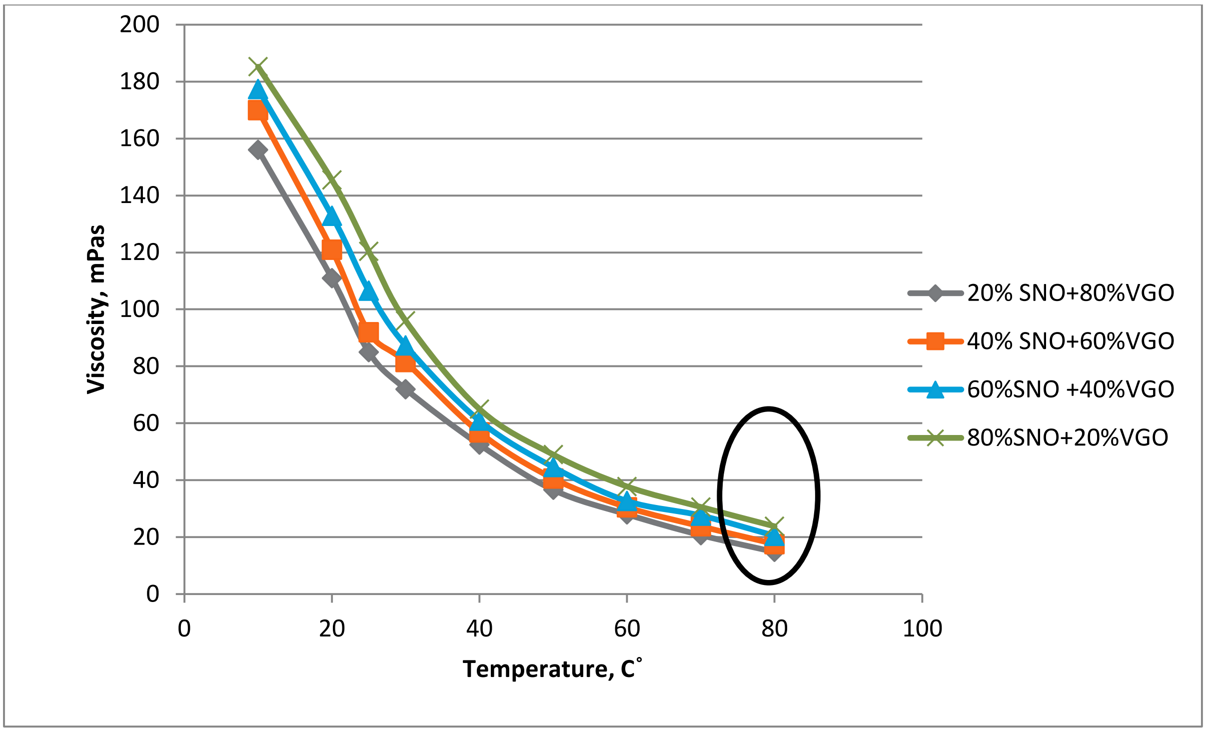

Figure 4. 1 Viscosity vs temperature for different blends

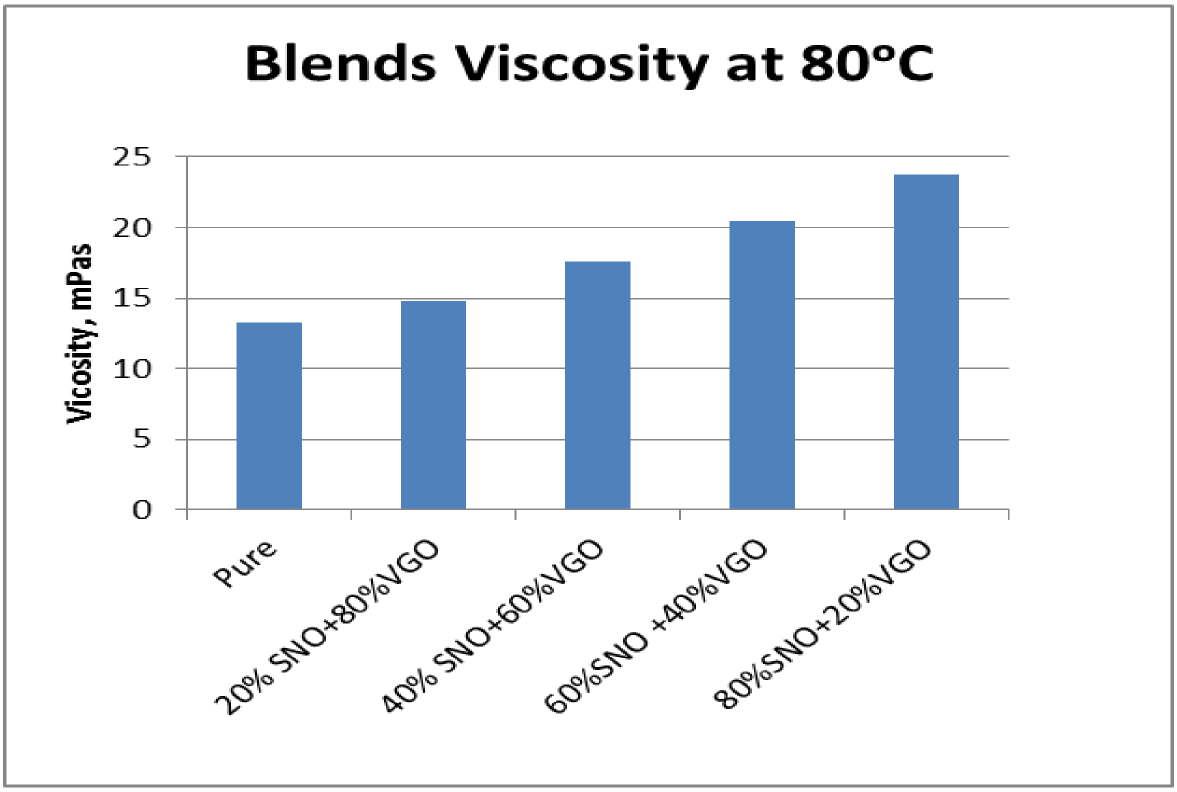

Figure 4. 2 Viscosity of different blends at 80C°

In the recent publication by Rafiq, Lv, Zhou, Ma, Wang, LiWang (2015), it has been reported that the vegetable oil has less viscosity values at all the temperatures compared to the synthetic oil. In addition, the value of the viscosity of the vegetable oil found to be about 10 (cSt). The current results are very comparable with the published ones and validated the experiments. In comparison to the soybean oil, the canola oil exhibits higher viscosity in relation to the viscosity of the soybean published by Quinchia, Delgado, Reddyhoff, GallegosSpikes (2014). This promotes the potential of using canola oil compared to the soybean oil. Furthermore, the current results shows that the addition of the synthetic oil can improve the viscosity by about 76%. The increase in the viscosity with the addition of the synthetic oil can be due to the fact that the synthetic oils have the additives such as EVA which significantly can improve the viscosity as reported by Quinchia et al. (2014) and (Alotaibi & Yousif 2016). Accordingly, the viscosity results support the potential of using canola oil as lubricants under the consideration of that the viscosity required should be in the range of 60 (cSt) at the temperature of 40 ºC.

In the following sections, the impact of the prepared blends on the wear and frictional behaviour of mild steel will be discussed. The wear results are presented in different forms to gain better understanding to the wear behaviour of the material.

4.3 WEAR BEHAVIOUR OF MILD STEEL

In the following section, the wear behaviour of the mild steel will be discussed in term of the influence of operating parameters, considering different blends of oil. In addition, the SEM of the worn surfaces are discussed at the end of this section. Compression with previous works is introduced as well.

4.3.1 Pure vegetable oil as lubricant

Weight loss of the mild steel samples against sliding distance under the pure vegetable oil lubricant conditions is presented in Figure 4.3. The figure shows that the increase in the sliding distance increases the weight loss. In fact, this is a factual phenomenon, the increase in the sliding distance increases the removal of the materials form the surface of the soft rubbed part which is the mild steel in this case. This results have been demonstrated by many articles such as (Vasyliev 2015; Zheng, Zhang, Li, Gong &Yin 2015). The sliding distance increases linearly the weight loss which is well known fact since there is an integration and adoption process between the rubbed surfaces, (Yousif & El-Tayeb 2008). To clarify this further, the wear data is represented in another form wear which is the specific wear rate against the sliding distance.

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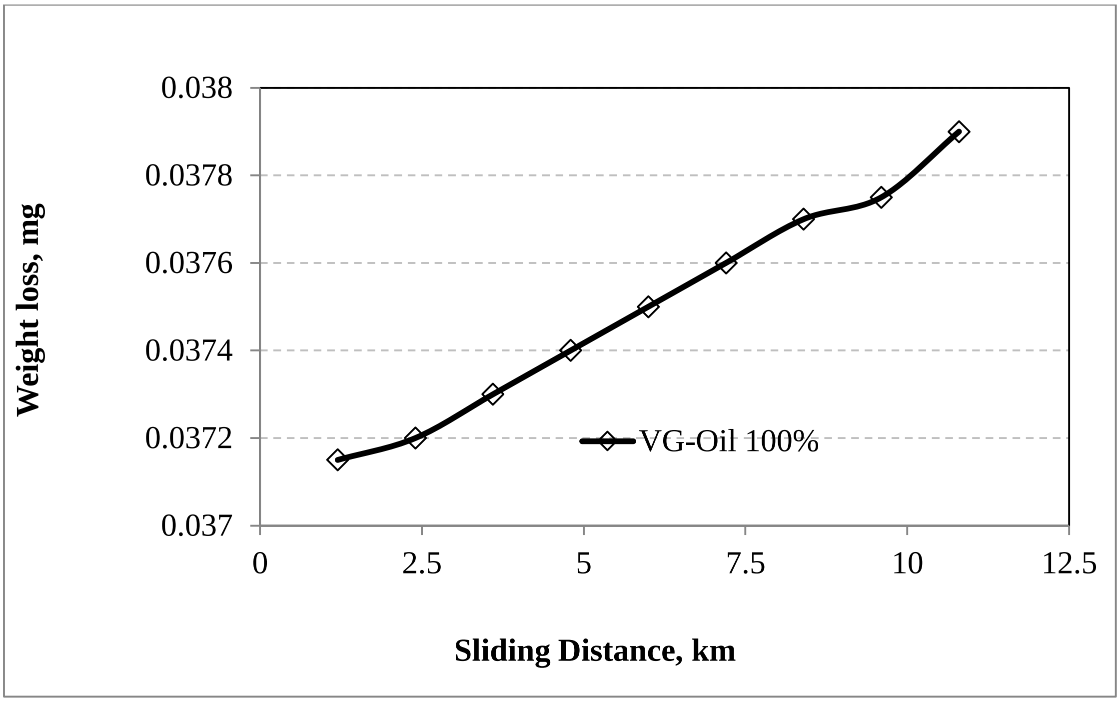


Figure 4. 3 Weight loss vs sliding distance of mild steel under pure vegetable oil

The specific wear rate represents the volume loss of the materials with respect to the applied load and the sliding distance. This may assist to understand the adoption of the sliding surfaces with the increase of the sliding distance or the rubbing time. Figure 4.4 displays the specific wear rate against the sliding distance of mild steel under the pure vegetable oil lubricant condition. The specific wear rate start at high level and then drops. However, at higher level of sliding distances there is no much drop in the value of the specific wear rate. At the first stage of the rubbing process, running in procedure is taking place. In other words, the adoption between the two surfaces is taking place for the integration of the surfaces. Further sliding (above 5 km), there is a steady state in the reduction of the specific wear rate which represent the steady state of the rubbing process. In other words, the removal of the materials with respect to the sliding distance remains contacts. It should be mentioned here that the steady state of the specific wear rate is the value in which the designed consider in component manufacturing. Such trend is common in metals and polymers since there is no much modification on the interface or the rubbed surfaces during the sliding. This behaviour is recently reported on two different types of steel, (Lindroos, Valtonen, Kemppainen, Laukkanen, Holmberg &Kuokkala 2015; Ruiz-Andres, Conde, de Damborenea &Garcia 2015).

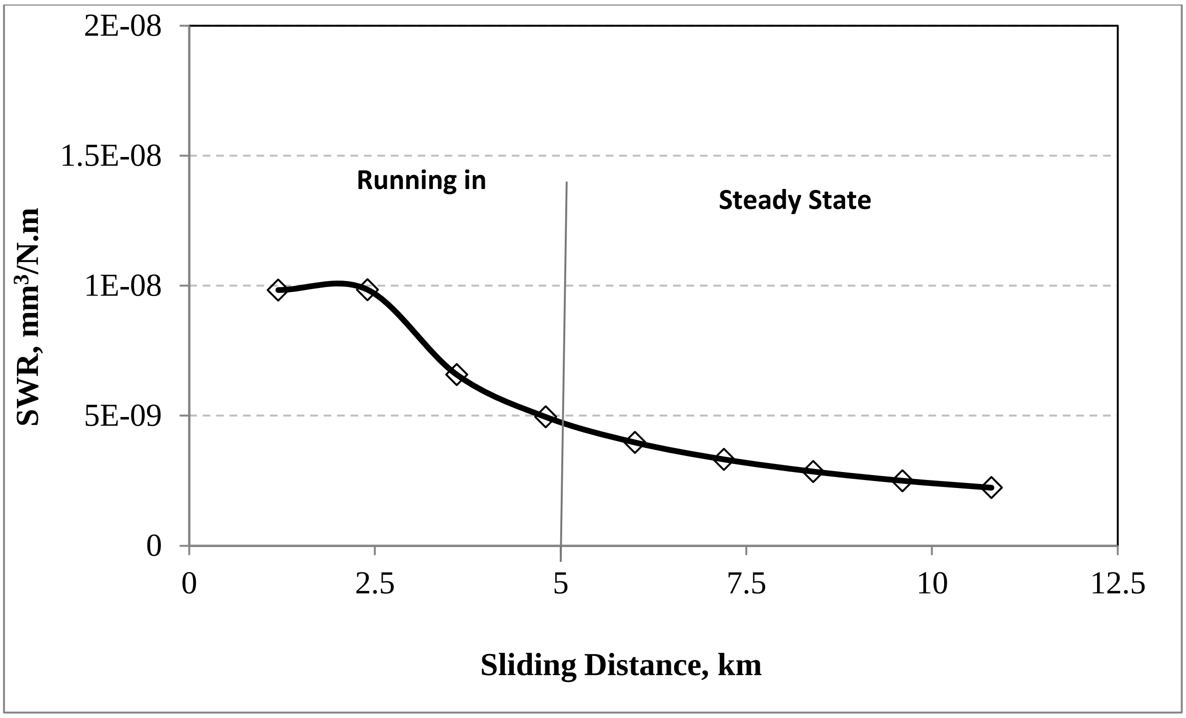


Figure 4. 4 Specific wear rate of mild steel under pure vegetable oil against sliding distance

To show the influence of the sliding speed on the wear behaviour of the mild steel, the specific wear rate of the mild steel against sliding velocity is generated and plotted in Figure 4.5. In Figure 4.5 the specific wear rate against speed of the counter face on mild steel under the pure vegetable oil lubricant condition shows that the specific wear rate high at the level of low velocity. From the viscosity data presented in Figure 4.2, the velocity of the pure canola oil is low. In other words, there is no enough lifting to the surfaces during the sliding. However, at high speeds, the pure canola oil can separates the milds steel form the stainless steel counterface at certain level which resulted in low removal of materials.

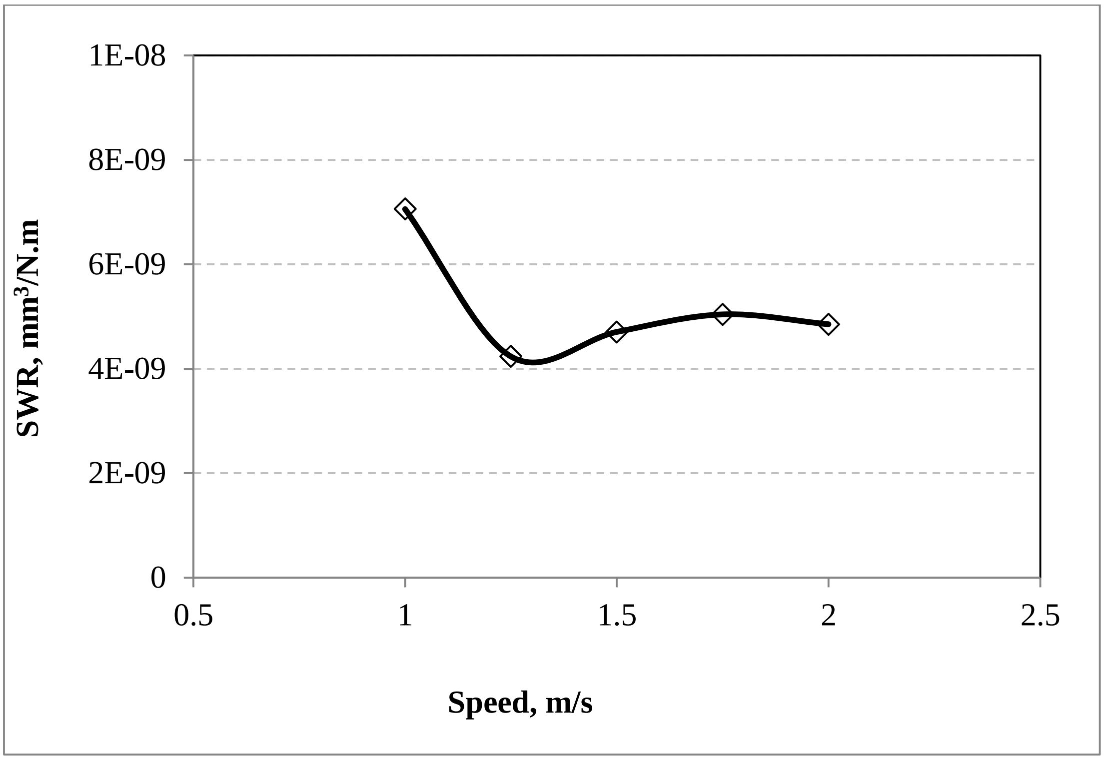


Figure 4. 5 specific wear rate of mild steel under pure vegetable oil vs speed.

The influence of the applied load on the he specific wear rate (SWR) is repressed in Figure 4.6 under the pure vegetable oil lubricant condition. From this figure, the specific wear rate drops with the increase of the applied load from 100 N to 140 N and then boosts at intermediate value of the load of 180 N followed by a sharp drop at very high applied load of 200 N. It should be mentioned here that the increase in the applied load has proportional relation to the material removable in term of the weight loss. However, due to the relation between the specific wear rate and the applied load, it is very difficult to correlate that. his scatter measurements of the specific wear rate has been avoided by many published works in which the data were presented in term of weight loss such as (Alidokht, Abdollah-zadeh & Assadi 2013), or in volume loss such as (Wimmer, Laurent, Mathew, Nagelli, Liao, Marks, Jacobs &Fischer 2015). On the opposite, Chin and Yousif (2009) reported similar scattered values of specific wear rate when the polymeric composites were tested against stainless steel at different applied loads. Based on this arguments, the current results is in agreement with the reported works.

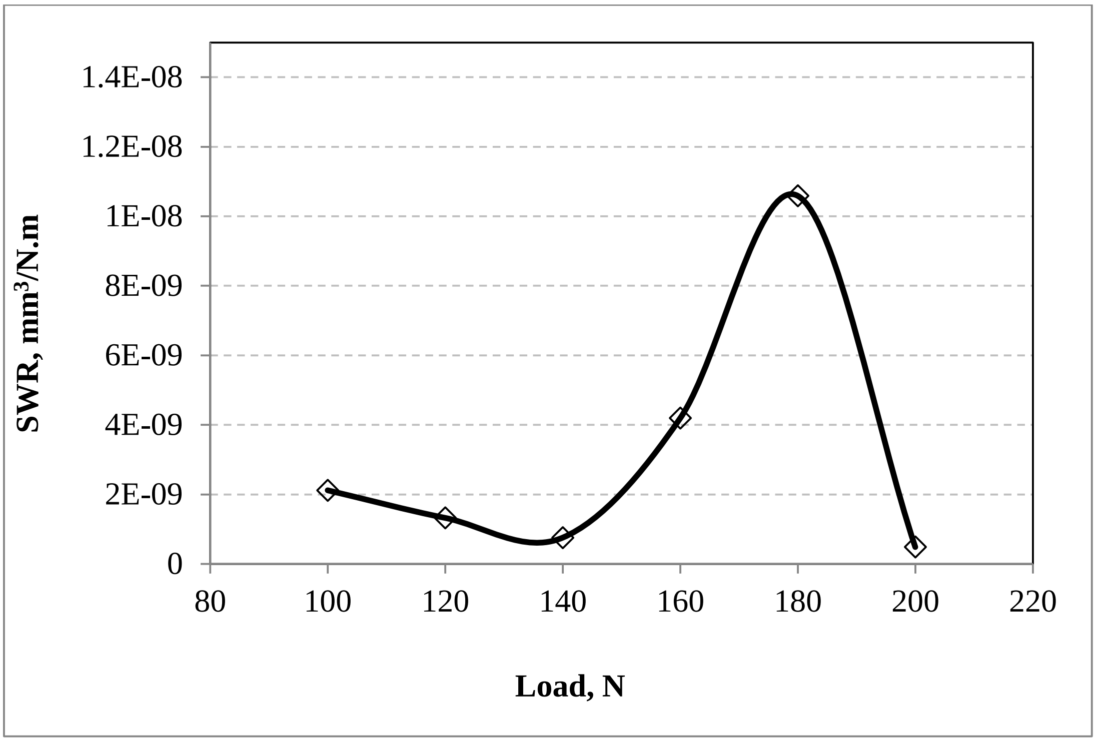


Figure 4. 6 effect of load on wear behaviour of mild steel using pure vegetable oil.

4.3.2 Wear behaviour of Mild steel under lubricant condition of (20% synthetic & 80% Canola)

This sections is similar to the above one expect the lubricant characteristics are different since the results in this section generated under the blend condition of 20% Synthetic oil and 80% canola oil. The results are presented in similar manner to the previous section. In other words, the results of the wear will be studied udner different operating parameters.

With respect to the weight loss against the sliding distance, Figure 4.7 shows the weight loss vs sliding distance on mild steel under the 20% synthetic blended with 80% of canola vegetable oil lubricant. It can be seen that the trend of the weight loss is similar to the one exhibited in the previous section in Figure 4.3 when the pure canola oil used as lubricant since increase the sliding distance increases the accumulated weight loss. This has been explained comprehensively in the previous section in which the material removal is in a proportional ration with the sliding distance and has been justified and agreed with the literate. However, it should be mentioned here the differences between the previous and this results is that the lubricant viscosity is higher than the previous conditions which may impact on the values of the wear. This will be comprehensively explained in the last section of the wear results (Section 4.3.6).

Figure 4. 7 Weight loss of mild steel against sliding distance under the lubricant condition of 20% synthetic and 80 % canola oil blende

For the specific wear rate relation with the sliding distance for the mild steel under 20% synthetic oil mixed with 80 % canola, Figure 4.8 is plotted to displays the relation. The specific wear rate increases with the increase of the sliding distance. This is no usual representation of the specific wear rate with the sliding distances. The usual trend is the increase then followed by decrease and steady state. It appears that the main issue can be raised here is with the low specific wear rate at the short sliding distance.

This can be mainly due to the high viscosity of the blends compared with the pure canola which has shown the usual trend of the specific wear rate with sliding distance. (Figure 4.4). Despite of that, there may be a coating process took place at the initial stage of the rubbing which coated the mild steel and resulted in high reduction in the material removal. Such behaviour has been reported by Mat Tahir, Abdollah, HasanAmiruddin (2016) when palm kernel activated carbon–epoxy (PKAC–E) composite. Has been tested at elevated temperature. In that work, the reasons for the increase in the specific wear rate was due to the presence of the third body in the interface which could be the same reason here as well. However, due to the time limit of this project, the debris in the lubricant was not investigated which needs further study.

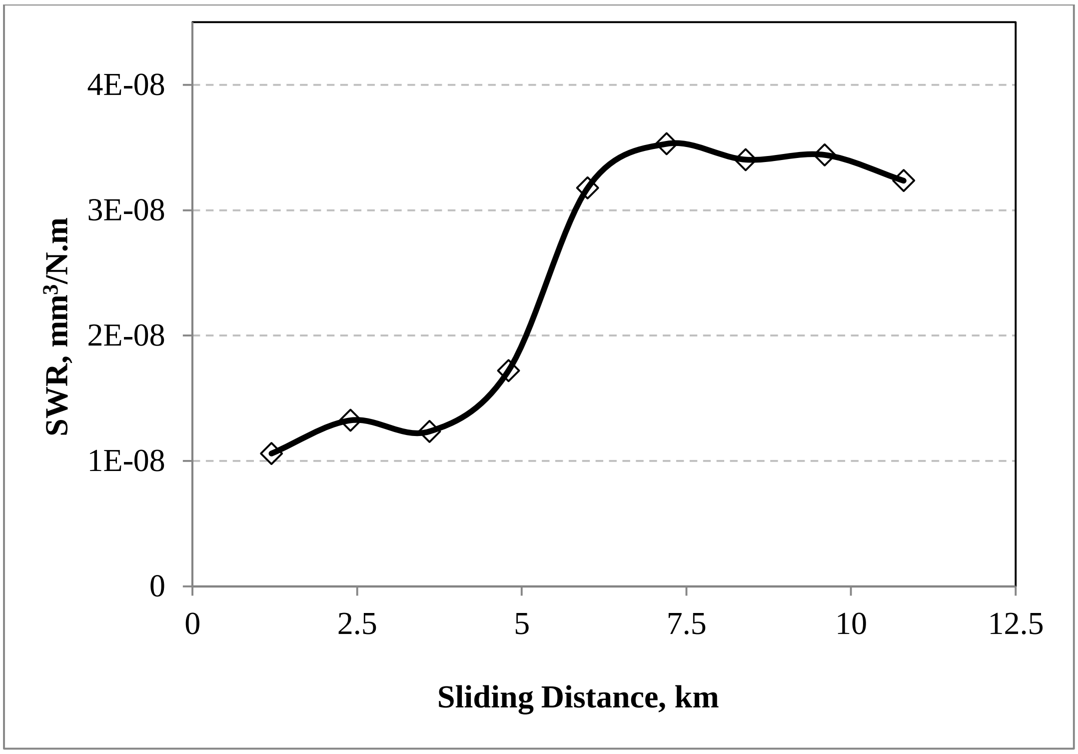


Figure 4. 8 Specific wear rate (SWR) of mild steel against sliding distance under the lubricant condition of 20% synthetic and 80 % canola oil blende

The influence of the sliding velocity on the specific wear rate of the milds steel under the 20% synthetic blend is displayed in Figure 4.9. Similar to the previous date of the pure canola oil (Figure 4.5), there is decrease in the specific wear rate with the increase of the velocity. The main reason for this is fact that the higher the speed the more lubricant will be in the interface. This can be confirmed with the measurement of the film thickness, however, the current machine is not capable of doing this. Therefore, it is highly recommended to measure the film of the lubricant in the interface for further understanding.

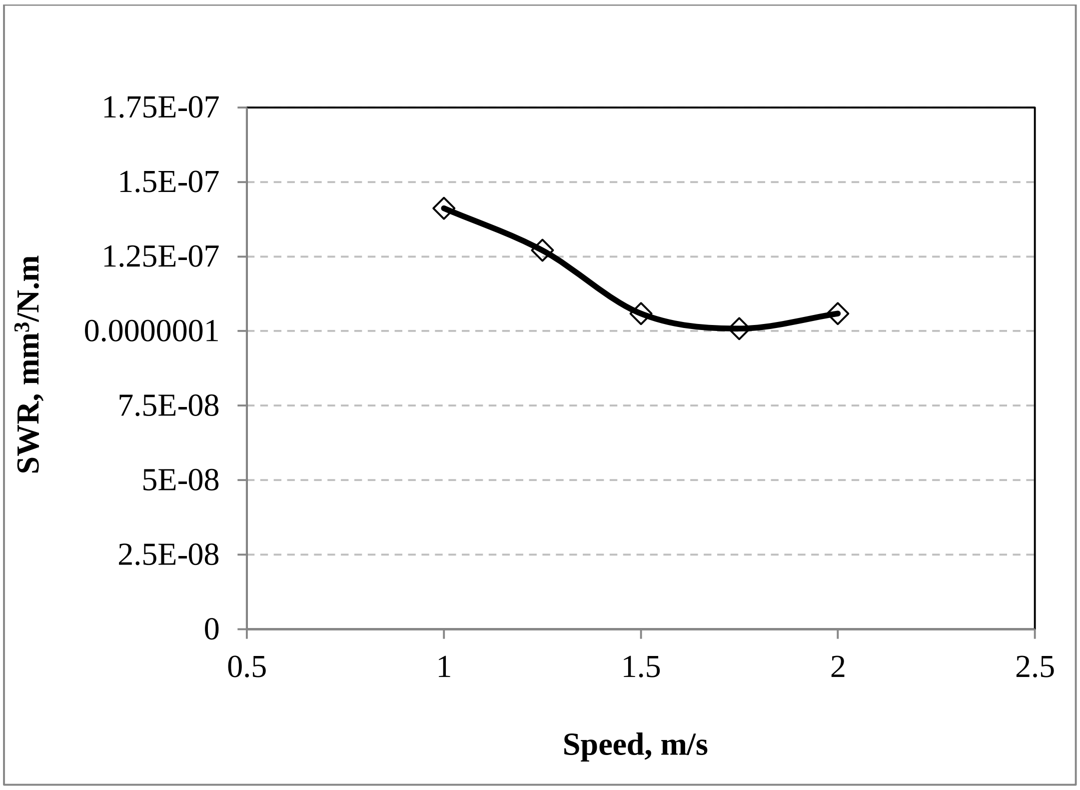


Figure 4. 9 Specific wear rate (SWR) of mild steel against velocity under the lubricant condition of 20% synthetic and 80 % canola oil blende

In the previous section the applied load impacts on the specific wear rate was not remarkable since the data was scattered (Figure 4.6). In this section, Figure 4.10 displays the specific wear rate vs load applied on the mild steel under the 20% SN and pure canola oil lubricant condition showing similar trend to the previous one. The discussion given in the previous section is similar to this section. Despite of this fluctuation in the data, the differences in the specific wear rate is very small which is in power of 10^{-8} In the design of component, it can be said that there is no influence of the applied load on the wear behaviour of the mild steel since this is not remarkable difference in the values of the specific wear rate, (Bayer 2004).

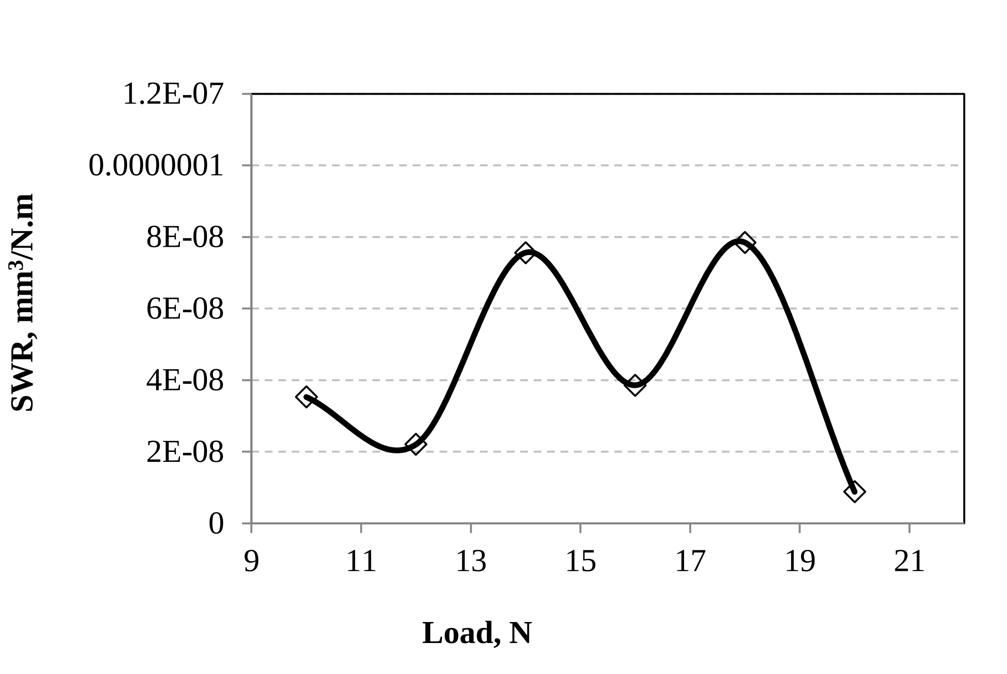


Figure 4. 10 Specific wear rate (SWR) of mild steel against applied load under the lubricant condition of 20% synthetic and 80 % canola oil blende

4.3.3 Wear behaviour of Mild steel under lubricant condition of (40% synthetic & 60% Canola)

In this section the wear performance of the mild steel under the lubricant condition of 40 % synthetic oil blend will be discussed. The materials removal form the mild steel during the rubbing process under the condition of the 40 % synthetic oil blend in relation to sliding distance is plotted in Figure 4.11 as the weight loss vs sliding distance. Similar to previous related sections when pure canola (Figure 4.3) and 20 % synthetic oil blend (Figure 4.7), the weight loss of the mild steel increases with the increase of the applied load due to the initial removal of the material from the surface. It should be explained here that at the initial stage, the rubbed surfaces have a tips which is easily can be removed away (high weight loss) and after a while the surfaces undergoes pure adhesive wear. Scherge, Linsler and Schlarb (2015) thoroughly discussed and explained this stage when they tested different metal-metal contacts under lubricant contact conditions. However, in that work the main focus was on the running in stage with respect to the friction coefficient which may give the same interpretation. In addition, the frictional results in the coming section will help in further understanding.

Figure 4. 11 Effect of sliding distance on mild steel against weight loss.

Figure 4.12 shows the specific wear rate against the sliding distance of mild steel under 40% SN and the pure vegetable oil lubricant condition. The figure shows fluctuations in the value of the specific wear rate, whoever, it should be mentioned here that the fluctuation in term of value is very minor since the range of the specific wear rate is in about ±0.25 10^{-8}. As mentioned previously in section 4.3.2, such amount in the component design is neglectable. In other words, it can be said that there is very minor influence of the sliding distance onto the specific wear rate of the mild steel. This can be due to the increase of the synthetic oil compared to the previous sections. In the synthetic oil as mentioned in chapter 3, there are some additive such as EVA which act as coating agent to prevent the removal of the materials.

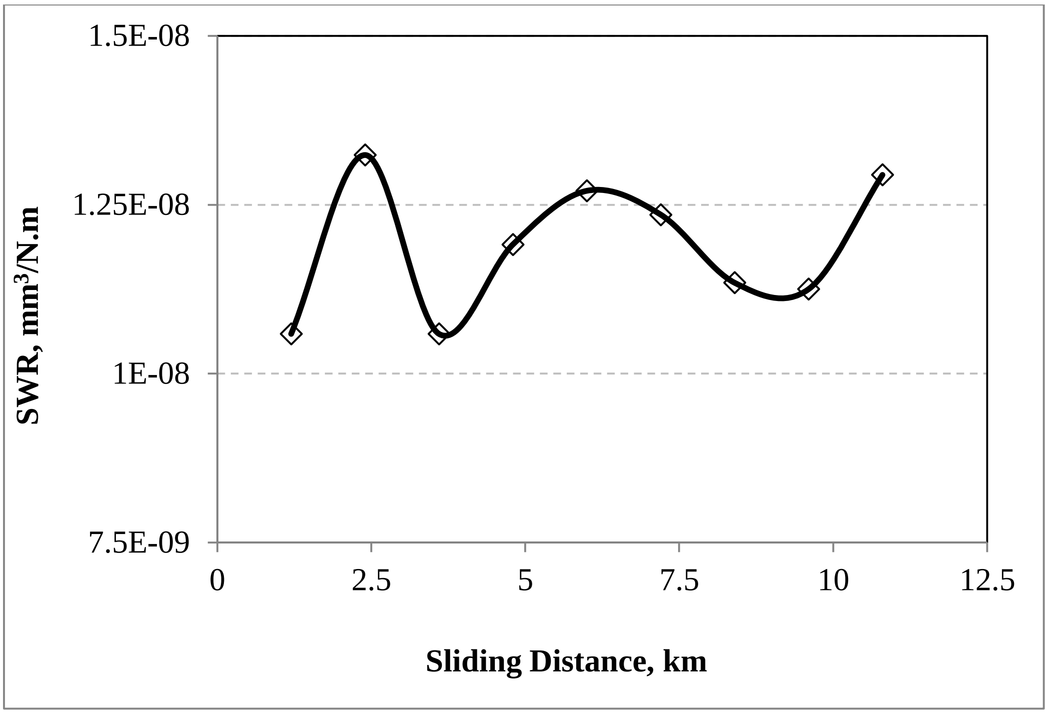


Figure 4. 12 Present SWR vs sliding distance on mild steel.

Figure 4.13 introduce the specific wear rate against sliding velocity of the counter face on mild steel under 40% synthetic oil blend lubricant condition. The specific wear rate start at high level and then drops. In general, the figure indicates that the increase of the sliding velocity drops the specific wear rate. In Figures 4.5 and 4.9 for pure canola and 20% synthetic oil blend lubricants respectively, the trends of the specific wear rate in relation to the velocity are the same as the one presented in this section for the 40 % synthetic oil blend. Similarly, the increase in the velocity encourage the lubricant to flow in the interface in which the lubricant act as separation agent. Despite of that, there is a removal of materials in very small amount which is presented in 10^{-9} value.

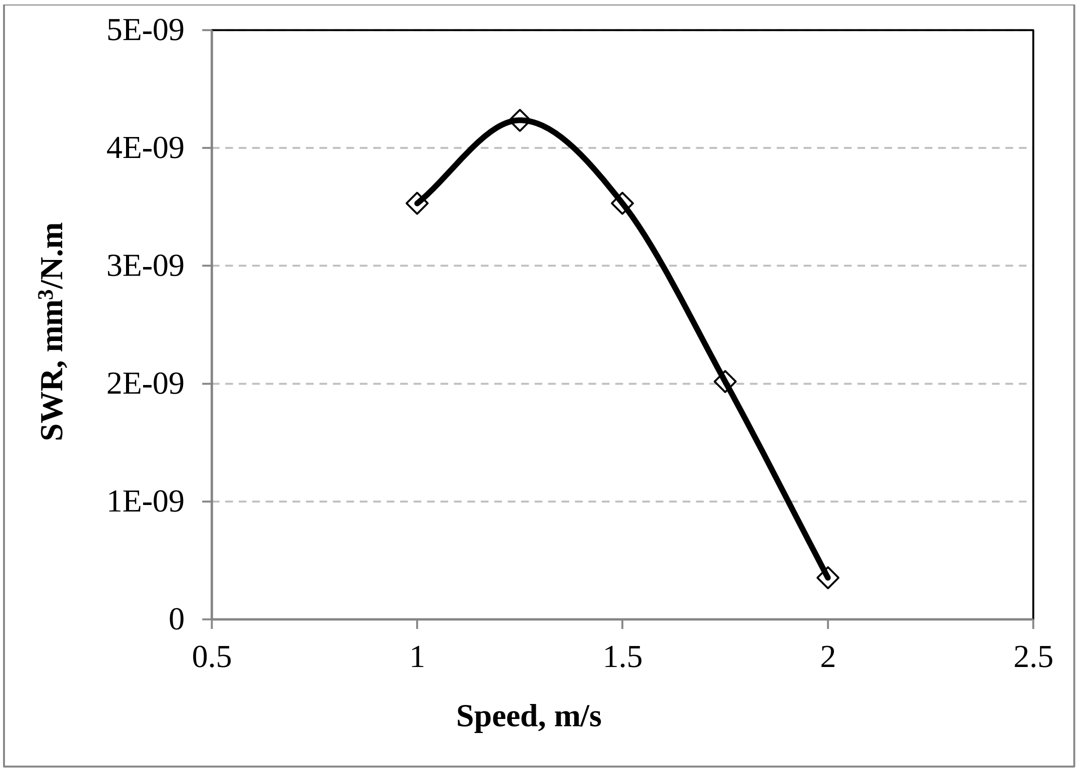


Figure 4. 13 Specific wear rate of mild steel vs speed

Figure 4.14 represent the specific wear rate against load applied on the mild steel under 40% synthetic oil blend. The specific wear rate starts at high level and then decreases to a low level. However, if we determine the weight loss only, one can say that the increase in the applied load increase the material removal. In term of material removal with respect to the applied load values, there is a drop in the specific wear rate. The value of the drop in the specific wear rate is about 5 10^{-10} mm^3/N.m.

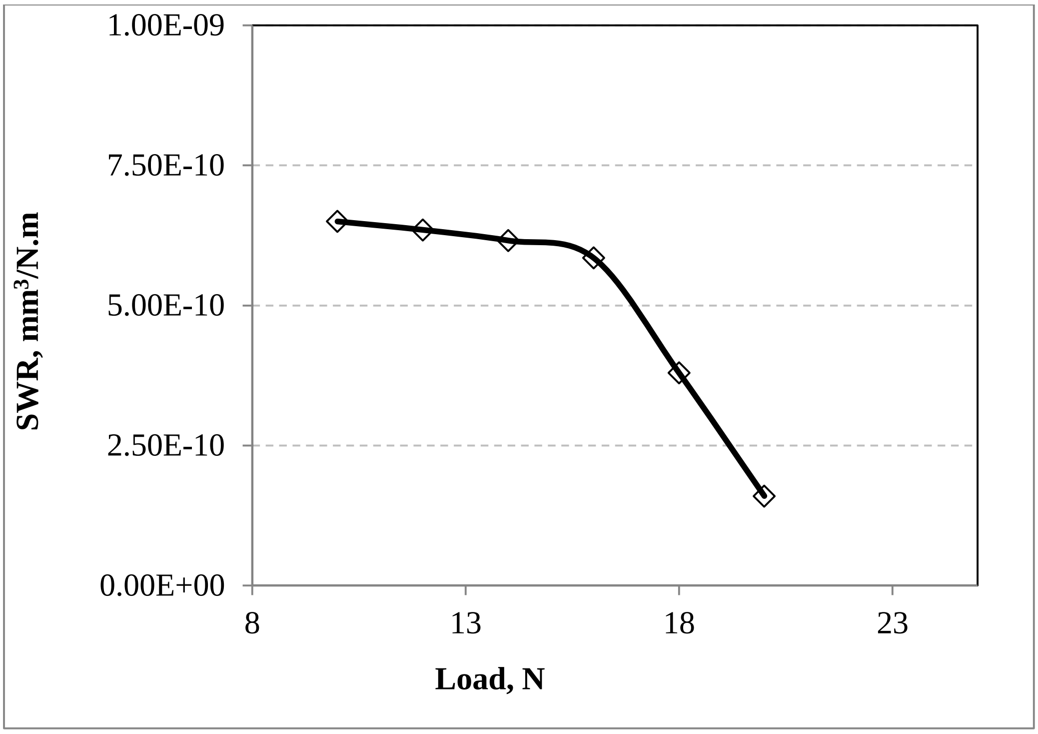


Figure 4. 14 Effect of different operating parameters on wear behaviour of mild steel.

4.3.4 Wear behaviour of Mild steel under lubricant condition of (60% synthetic & 40% Canola)

Figure 4.15 presents the weight loss vs sliding distance on mild steel under the 60% synthetic oil mixed with 40% canola oil lubricant condition. Basically the increasing of sliding distance is leading to increase the weight loss. The linear relation between the weight loss and the sliding distance is very clear in this figure which is similar to the ones shown before when pure canola, 20% synthetic blend and 40% synthetic blend as well. The reason for this behaviour has been explained in detail in the previous sections. In term of the performance of the mild steel under this lubricant blend compared to other, this will be explained in section 4.3.6 since all the trend of the specific wear rate of the blends are plotted against sliding distance in one figure.

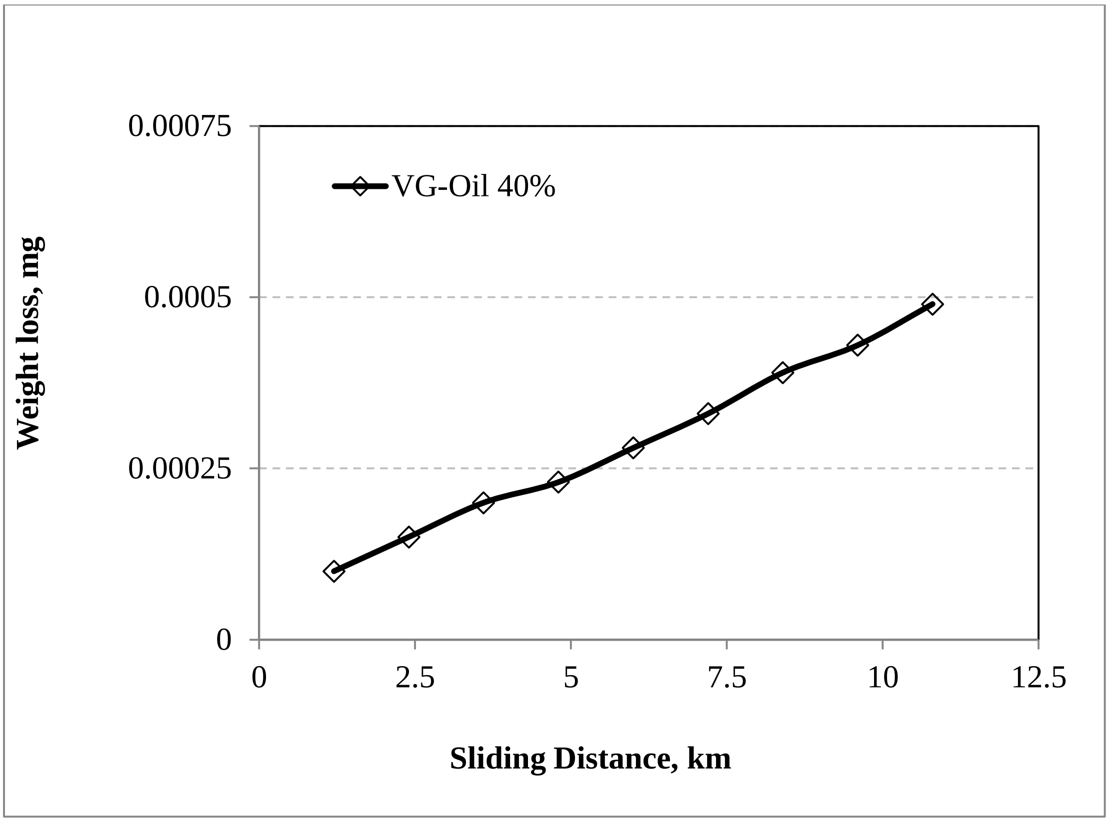


Figure 4. 15 Effect of sliding distance on mild steel against weight loss.

Figure 4.16 displays the specific wear rate against the sliding distance of mild steel under 60% SN and the pure vegetable oil lubricant condition. The specific wear rate start at high level and take place on steady state. This is a typical behaviour of all the materials which represented by high material removal at the first stage showing the running in period followed by steady state which introduces the performance of the mild steel for long period under this blend. From this figure, it can be said that the specific wear rate of the mild steel under the steady stage is equal to 3 10^{-9} $mm^3/N.m$ after about 5 km sliding distance and greater.

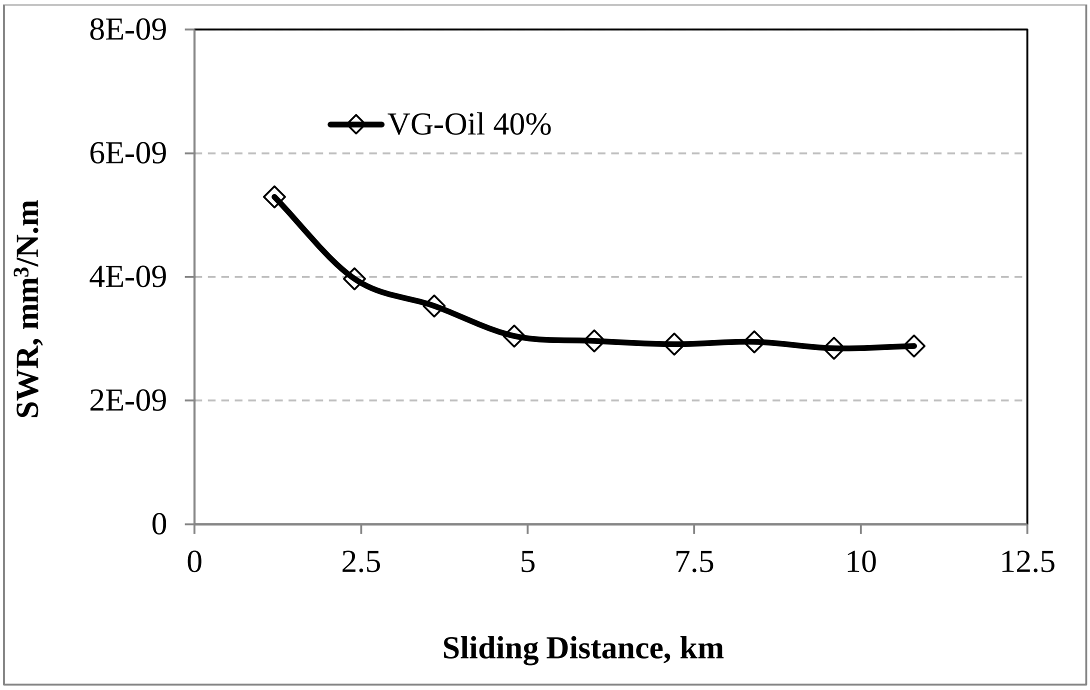


Figure 4. 16 Presents SWR vs sliding distance on mild steel.

Figure 4.17 Introduce the specific wear rate against velocity of the counterface on mild steel under 60% synthetic oil blend lubricant condition. The specific wear rate is in a waving state. In contrast to the previous results of the pure canola, 20 % synthetic and 40 % synthetic lubricants, the 60% synthetic oils shows not remarkable influence on the specific wear rate of the mild steel with respect to the velocity. This can be due to many reason such as the filth thickness, adhesion of the lubricant on the surface, or the washing of the debris in the interface. Based on the available data here, I can say that the high viscosity of this blend compared to low percentage of syntactic in other blends is the significant reason. The high velocity oil inter the interface and plays the main role in cooling down the area carry the debris and/or spreads the surface. Further investigation is needed to study the film thickness in the interface and the coating process on the mild steel during the rubbing procedure.

Figure 4.18 represent the specific wear rate against load applied on the mild steel under 60% synthetic oil. The trend of the applied load for this blend is similar to the previous ones for the pure canola, 20% synthetic and 40% synthetic.

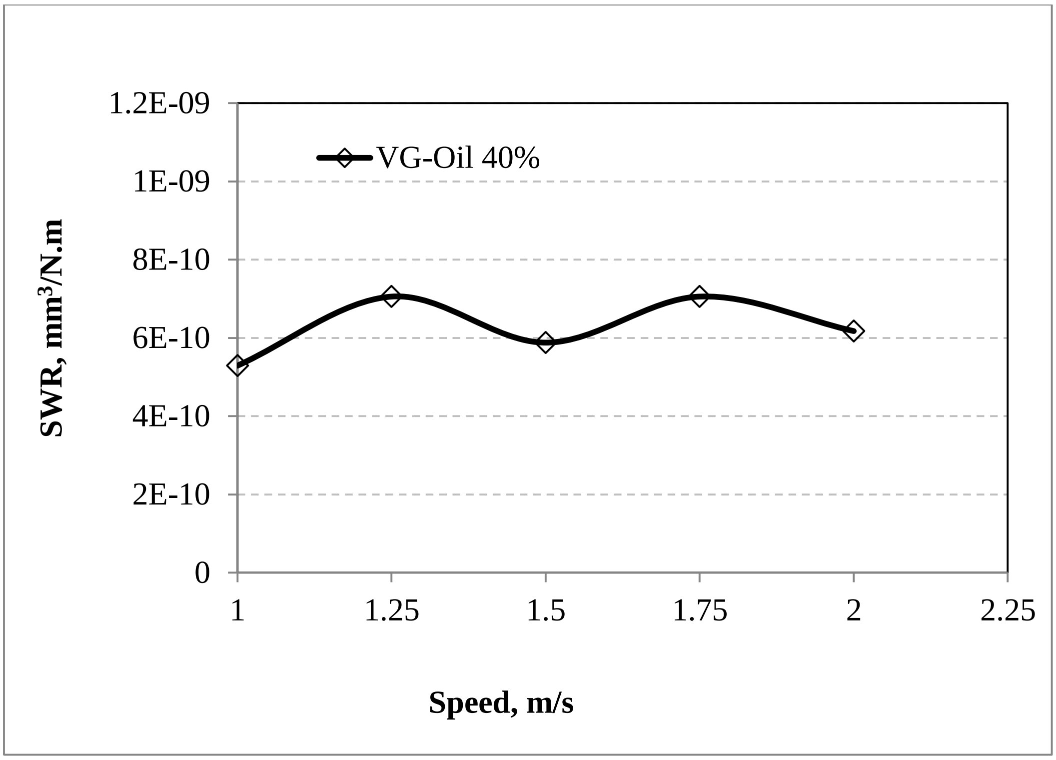


Figure 4. 17 Specific wear rate of mild steel vs speed.

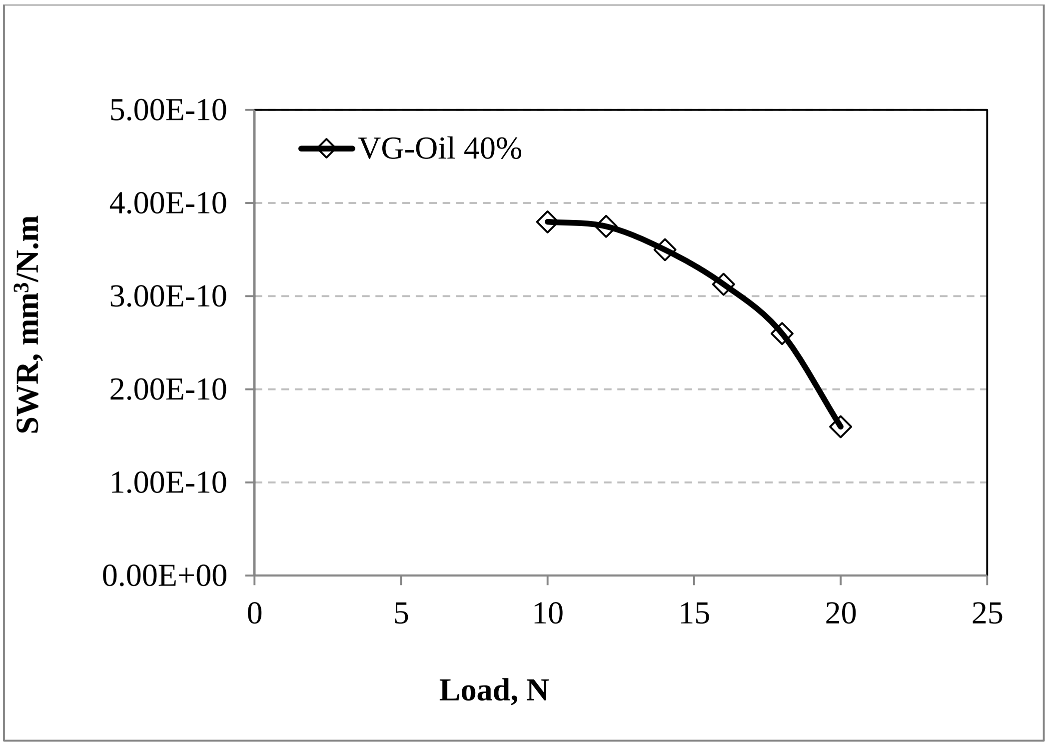


Figure 4. 18 Effect of different applied load on wear behaviour of mild steel

4.3.5 Wear behaviour of Mild steel under lubricant condition of (80% synthetic & 20% Canola)

The wear results of the mild steel sliding against stainless steel counterface under the lubricant condition of 80 % synthetic oil blended with 20 % canola oil is presented in Figures 4.19 to Figure 4.22 under different operating parameters. With regarding the to the weight loss, Figure 4.19 shows the weight loss vs sliding distance on mild steel under the 80% synthetic oil blend. Basically, the increasing of sliding distance is leading to increase the weight loss. This is similar trend to the ones shown previously when different blends have been used and the increase in the weight loss is a well-known fact.

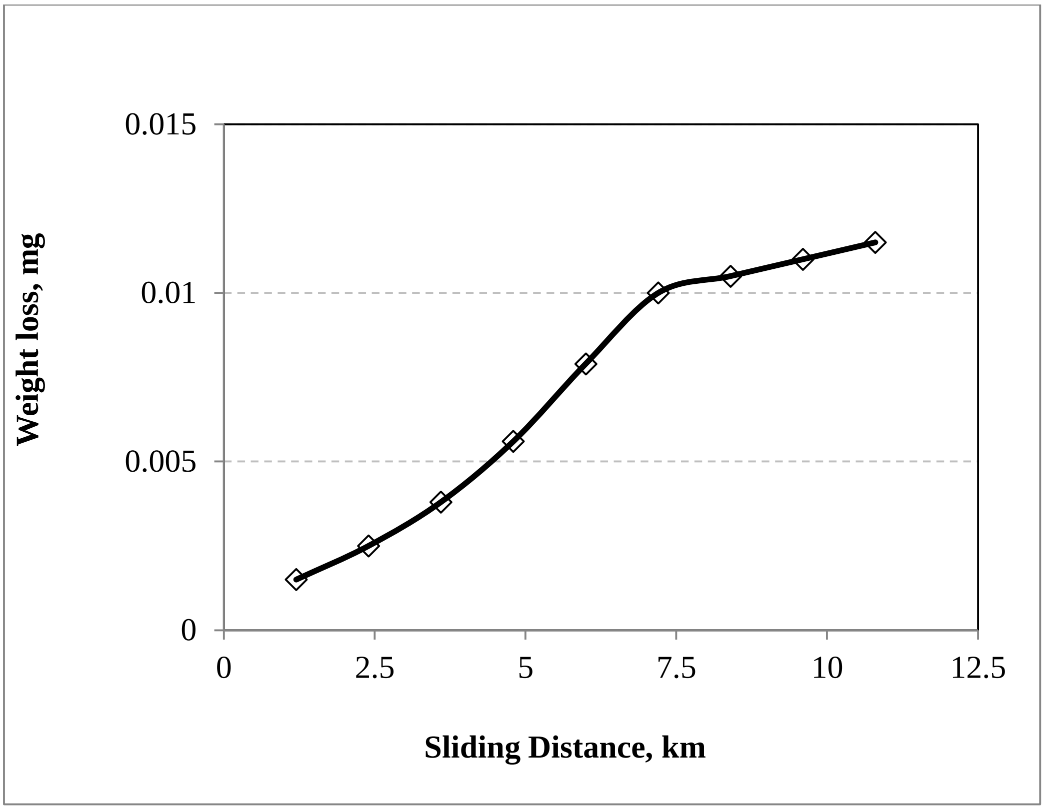


Figure 4. 19 Effect of sliding distance on mild steel against weight loss.

Regarding the influence of the sliding distance on the specific wear rate, Figure 4.20 displays the specific wear rate against the sliding distance of mild steel under 80% synthetic blend lubricant. The range of the specific wear rate can be seen at about 8 10^{-8} $mm^3/N.m$. The variation in the specific wear rate is range of ± 2 10^{-8} $mm^3/N.m$.

in other words, I cannot see significant impact of the sliding distance on the specific wear rate. I would suggest that the reason of that is the high viscosity of the blends since it contains 80% synthetic which introduced the highest viscosity than the others, refer to Figure 4.2. At high viscosity, the possibility of separating the two rubbed surfaces of the mild steel and the stainless steel is higher than the ones at low viscosity. This may explain this results. Furthermore, this will be elaborated on in the next section.

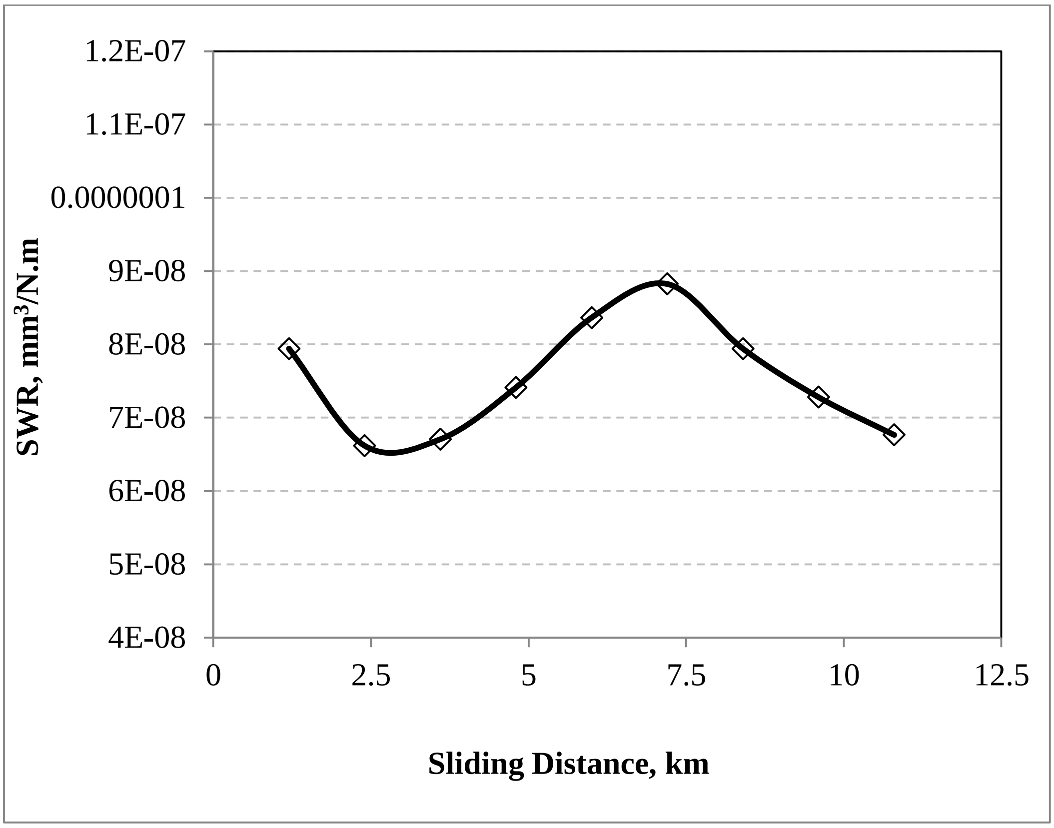


Figure 4. 20 Shows SWR vs sliding distance on mild steel.

Figure 4.21 represents the specific wear rate against sliding velocity of the counterface on mild steel under the lubricant condition of 80% synthetic oil mixed with 20% canola oil. In general, it can be seen from this figure, the increase in the velocity increase the specific wear rate. It has been mentioned that the lubricant used to gain this results has high viscosity (Figure 4.2). The high viscosity associated with high speed in the interface can give negative impact on the wear rate of the materials, (Bowden & Freitag 1958; Alotaibi & Yousif 2016).

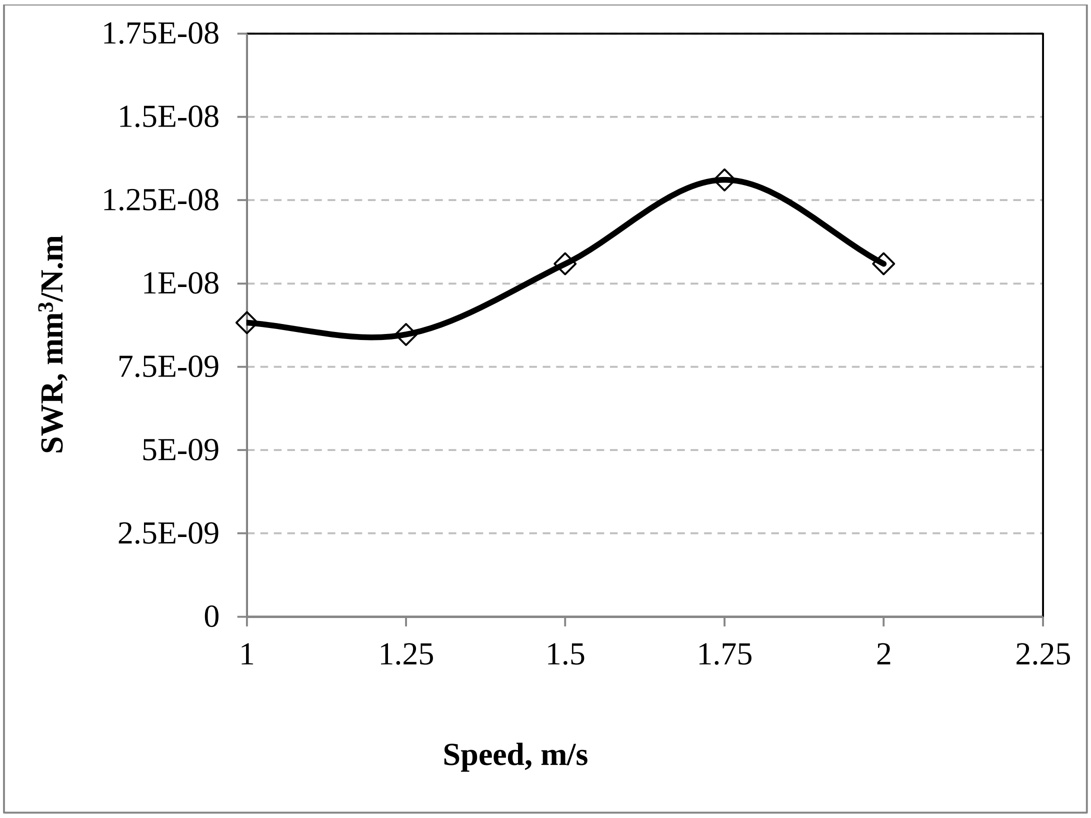


Figure 4. 21 Presents SWR vs sliding distance on mild steel.

Figure 4.22 displays the specific wear rate vs load applied on the mild steel under the 80% synthetic oil blend. The increase in the applied load shows decrease in the specific wear rate and this behaviour has been exhibited by the mild steel previously under the other blends lubricant conditions. The reason for this has been explained previously as well.

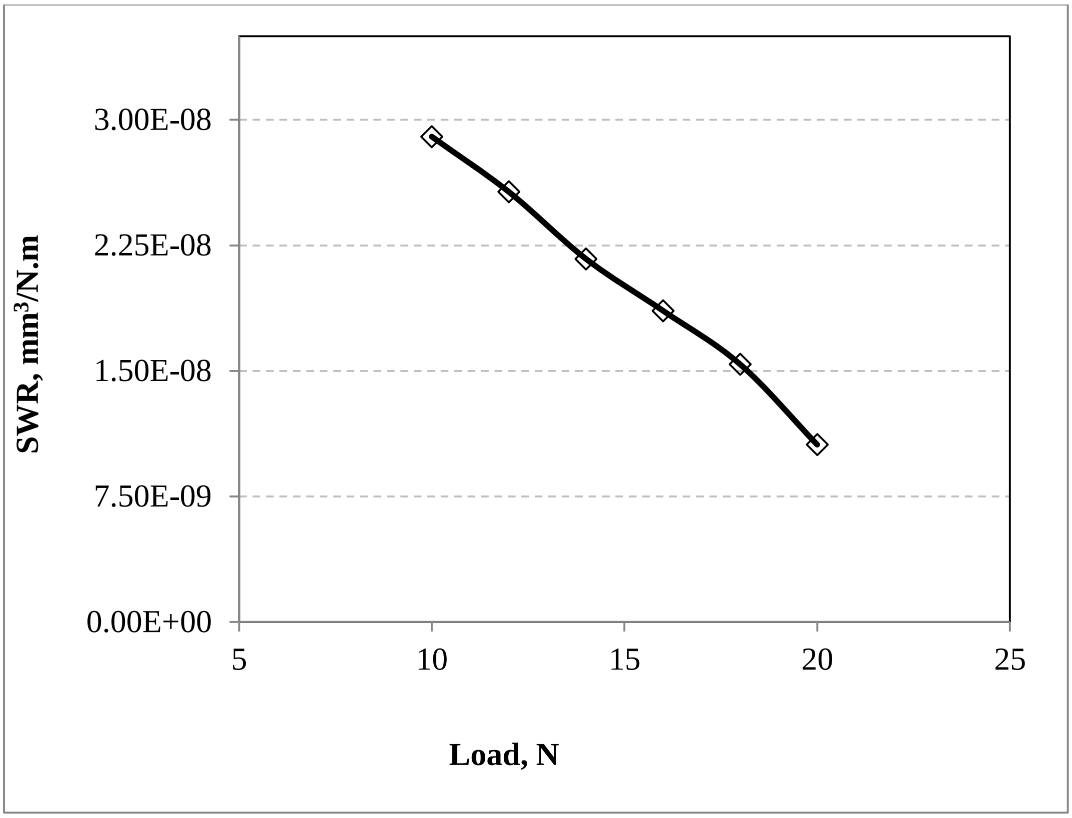


Figure 4. 22 Effect of load applied on SWR for mild steel.

4.3.6 Effect of synthetic oil on wear behaviour of the MS'

To show the influence of different blends on the specific wear rate of the milds steel owing to optimize the mixing ratio, the specific wear rate against sliding distance of the mild steel under all types of blends is plotted in Figure 4.23. You can see that there is comparable results mong all the blinds. The pure canola vegetable shows intermediate behaviour compare to the synthetic especially at the steady state condition. Combining the two oils together seems to have different effects, since the low percentage of the synthetic oil significantly improve the lubricant properties of the oil which resulted in lowest specific wear rate compared to other. However, the addition of high amount of the synthetic oil worsen the lubricant properties which showed high removal of materials form the mild steel. The chemical reaction between the synthetic oil and the vegetable need an attention which I am not familiar with at this stage. Recommendation is given in the future work section. As the main objective of the work is to study the potential of canola oil as lubricant in comparative to the commercial lubricant, I can say that the canola oil has very good potential to replace the synthetic oil based on the tribological experimental results. This is for a specific working condition in which the mild steel in rubbing condition against stainless steel. This application can be found in the two strokes engine. Despite of that, the degradability of the oil needs to be investigated as well to identify the life time of the oil.

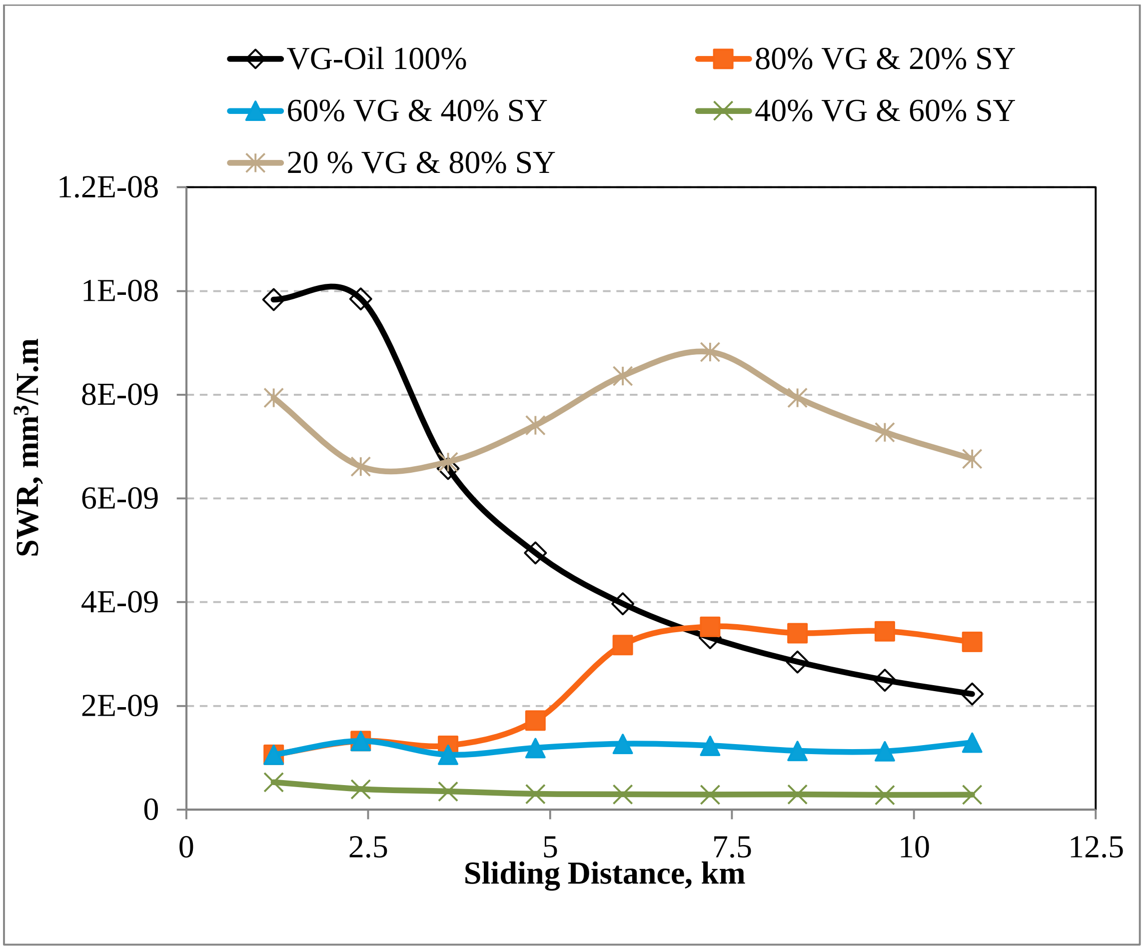


Figure 4. 23 Behaviour of SWR vs sliding distance for blend on the mild steel

4.4 FRICTION BEHAVIOUR OF MILD STEEL IN TERM OF FRICTION COEFFICIENT

The addition of the synthetic oil significantly influence the lubricant properties which was clear in the viscosity level and wear behaviour of the mild steel which have been addressed in the previous sections. The main findings of the previous section and related to this sections are the high viscosity of the blends with the increase percentage of the synthetic oil, and the comparable wear performance of the mild steel under all the blends lubricant conditions. In this section, the friction coefficients of the mild steel are given under different blends lubricant conditions and operating parameter.

4.4.1 Frictional behaviour of Mild steel under pure canola lubricant

Figure 4.24 shows in the friction coefficient against the sliding distance of the mild steel under different applied loads and under the canola oil lubricant condition. From this figure, it can be seen that the steady state of the friction is pronounced after about 4 km. At the initial stage there is adaption between the surfaces which fluctuated the friction. With regards to the impact of the applied load, it can be seen that the high applied load shows less friction coefficient. However, the reduction in the friction is not that pronounced. On the other hand, the friction force at higher applied load is greater than the lower applied load. From the literature, there are some works shows that the friction reduces with the increase of the applied loads such as (Gultekin, Uysal, Aslan, Alaf, Guler &Akbulut 2010) and in some published work there is no remarkable effect of the applied load on the friction coefficient, (Kahn, Ernst & Heuer 2016). Gultekin et al. (2010) and Uyyuru, Surappa and Brusethaug (2007) inverse proportionality exists between the applied normal load and the measured friction coefficient due to that applied load leads to increase oxidation of the metal surfaces.

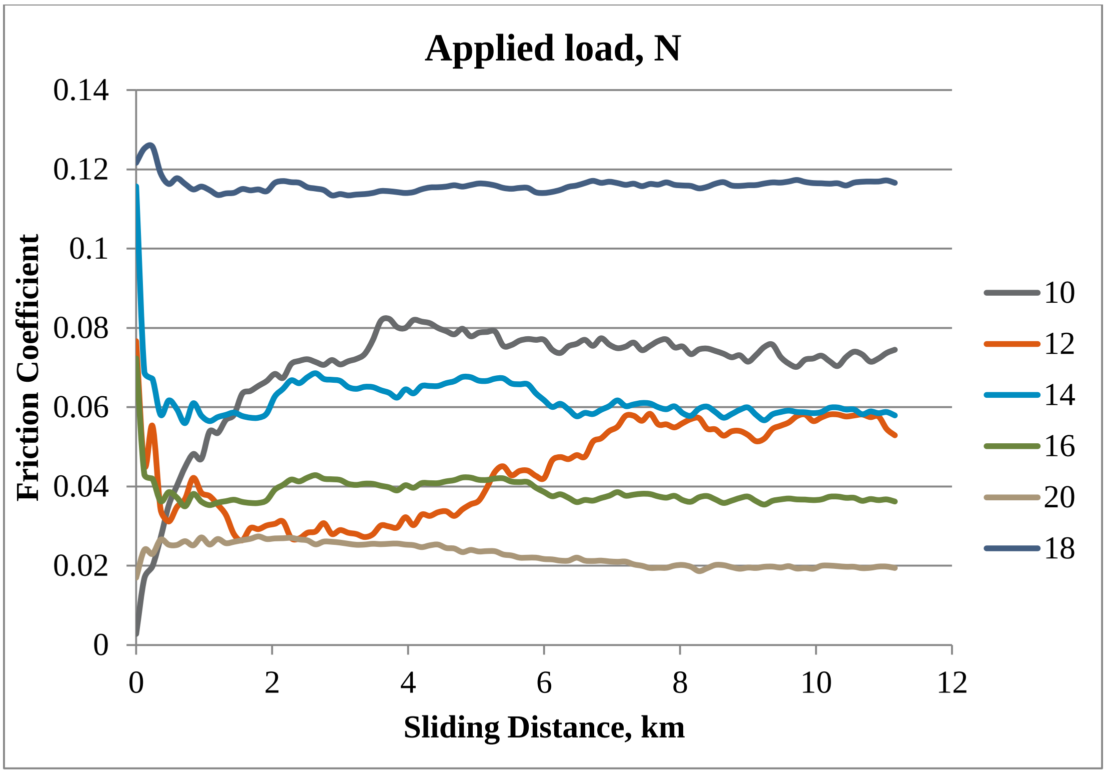


Figure 4. 24 Friction coefficient against sliding distance at different applied loads under pure canola oil lubricant conditions

The influence of the sliding velocity on the friction coefficient of the mild steel under the pure canola oil lubricant conditions is given in Figure 4.25 for different sliding velocities against sliding distance. The figure shows that the increase in the sliding velocity increases the friction coefficient. At high level of velocity, there is a great amount of lubricant can go into the interface which can causes high shear on the surface of the mild steel resulting in high friction coefficient. At the same time, Figure 4.5 showed that the high velocity reduces the wear. In tribological science, there is a fact says the high wear the less friction and the opposite is true as well, (Bhushan 2013a). This indicates that the current study is in agreement with the standard tribological facts.

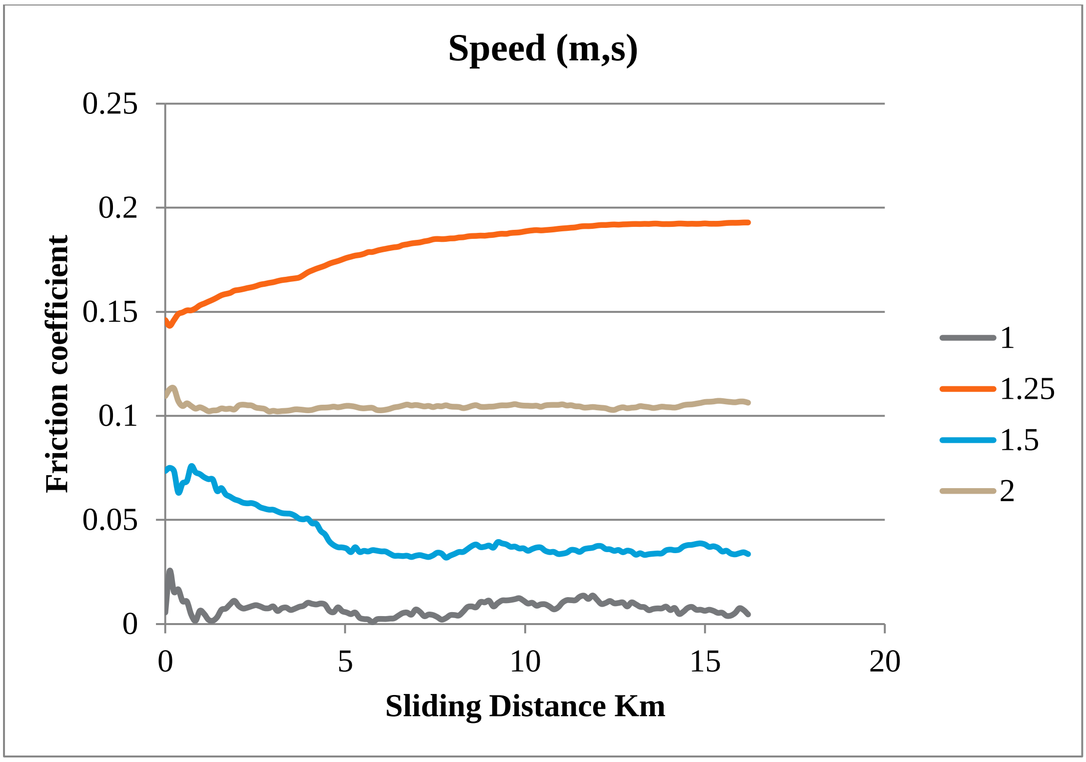


Figure 4. 25 Friction coefficient against sliding distance at different velocities under pure canola oil lubricant conditions

2.4.2 Frictional behaviour of Mild steel under lubricant condition of (20% synthetic & 80% Canola)

The friction coefficient of the mild steel under the 20 % synthetic oil blended with 80% canola is presented in Figure 4.26 at different applied loads. The friction coefficient seems to have high relatively value at the first stage of sliding (running-in) and then get steady state. This is the nature of the metal behaviour under sliding process since there are some obstacle (asperities in contact) in the movement of the bodies at the initial stage (Static-Friction) and once the asperities adhered and plastically disappeared, pure adhesive wear takes place, (Bhushan 2013b) .

Furthermore, the figure shows that the low applied load introduces relatively high friction coefficient compared with the high applied load. This has been explained in the previous section according to the tribological fact which is the high wear produces low friction. With this blend of 20% synthetic, the wear data in Figure 4.10 said that the high load of 18 N produced the low specific wear rate. However, there are some scattered points which is also be considered as normal since the tribological behaviour of materials depends on many parameters in the interface which cannot be predicted, (Lubrecht & Dalmaz 2004) .

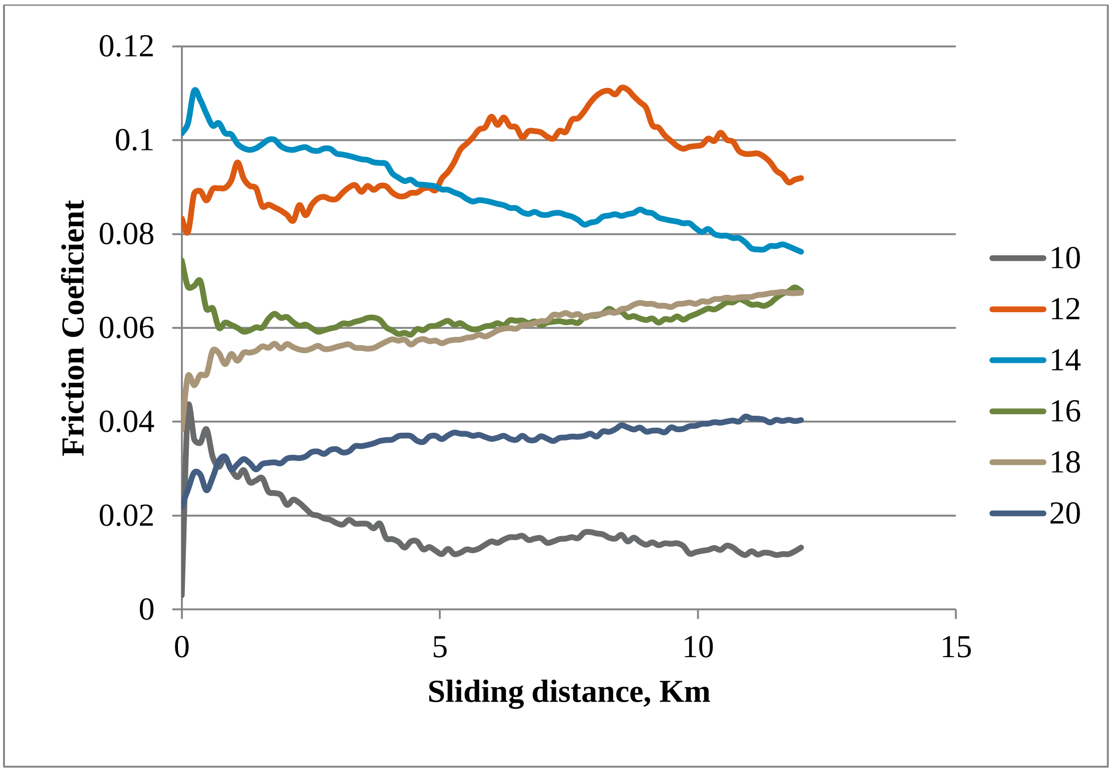


Figure 4. 26 Friction coefficient against sliding distance at different applied loads under 20 % synthetic oil blended with canola oil lubricant conditions

Figure 4.27 displays the relation between the frictions coefficients with the sliding distance at different sliding velocities for the mild steel under the 20 % synthetic oil blended with 80% canola oil. The figure shows that the low friction coefficient can be achieved at the low sliding velocity of 1 m/sec. the increase in the sliding velocity increases the friction coefficient and this is similar to the trend given in the previous section when the pure canola oil used as lubricant, Figure, 4.25. It is mentioned that the increase in the velocity can increase in the shear in the interface which leads to high frictional force.

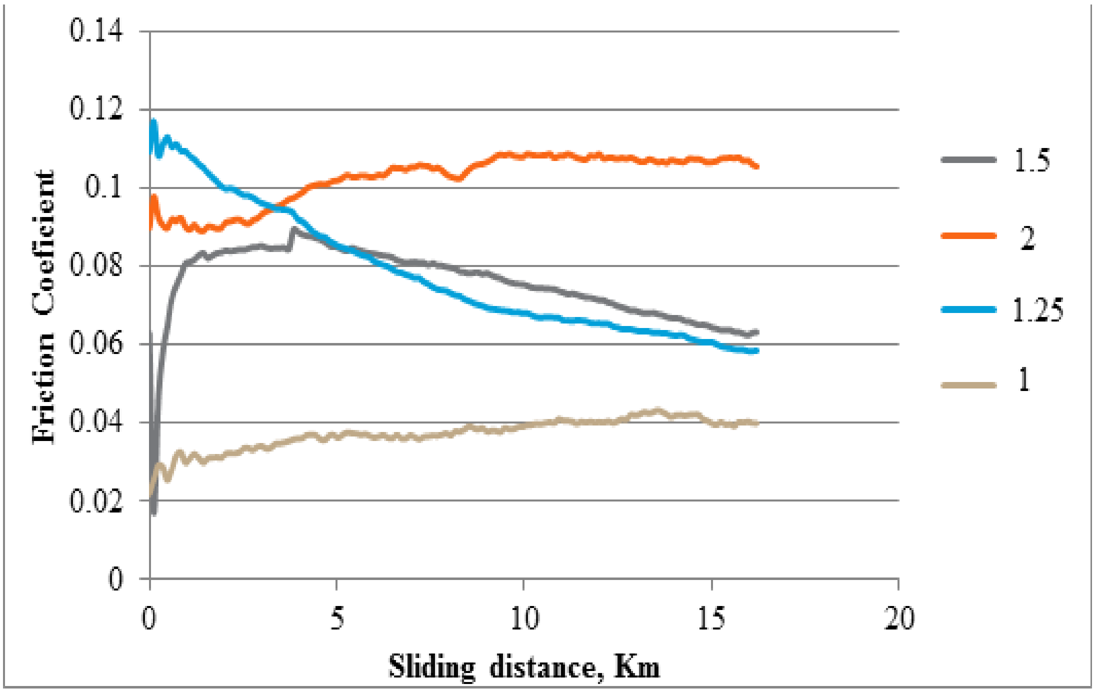


Figure 4. 27 Friction coefficient against sliding distance at different velocities under 20% synthetic oil blended with canola oil lubricant conditions

4.4.3 Frictional behaviour of Mild steel under lubricant condition of (40% synthetic & 60% Canola)

The friction coefficient of the mild steel against stainless steel counterface under the lubricant condition of 40 % synthetic oil blended with 60 % canola is presented in Figure 4.28 at different applied load with respect to the sliding distance. At the low level of the applied load, there is high friction coefficient value and with the increase of the applied load there's reduction in the friction coefficient. From the wear data presented in Figure 4.13, the specific wear rate was high at the low applied load and then dropped. This behaviour is strange compared to the previous ones and it contradict the fact that the high wear represented low friction. Despite of that, the difference in the condition of this results is the increase of the synthetic oil in the blend. I would suggest here that the increase in the synthetic blend may be the reason of this conflict in which the synthetic oil coated the surface of the mild steel and prevented it from the high removal of material at the high applied load. However, this should reduce the friction as well especially at low applied load. On the other hand, Gultekin et al. (2010) and Uyyuru, Surappa and Brusethaug (2007) reported that increase the applied loads reduces the friction coefficient which in agreements with the current results.

At this stage, I cannot given any thought or concept on the data since I need more information about the surfaces and the synthetic oil impact on the surface modification during the sliding. Due to the time limit of this project, I will recommended further study about this point in chapter 5

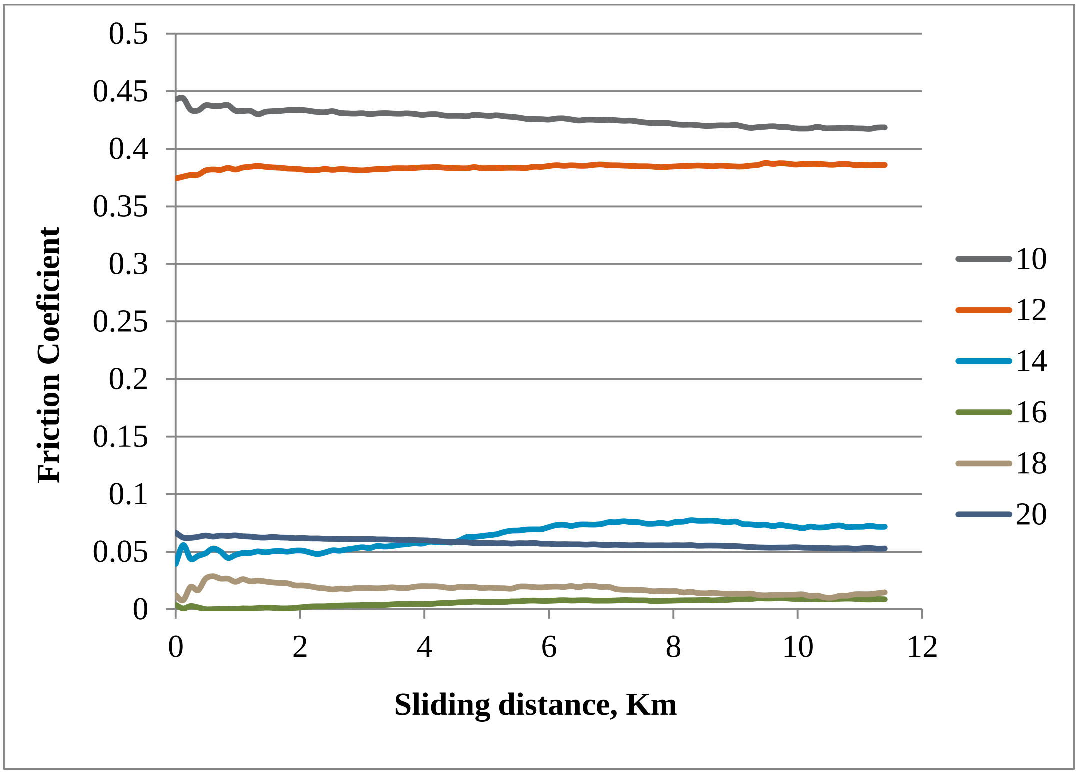


Figure 4. 28 Friction coefficient against sliding distance at different applied loads under 40 % synthetic oil blended with canola oil lubricant conditions

The effect of the sliding velocity on the frictional behaviour of the mild steel under the 40% synthetic oil blend is presented in Figure 4.29. The figure clearly shows that the increase in the velocity reduced the friction coefficient and this is opposite to the ones given in the previous section. In addition, Figure 4.13 shows that the increase in the velocity reduces the specific wear rate as well. It seems the 40 % syntactic blended lubricant significantly changed the trends of the friction, which required further study to identify the cause. Despite the fact that there is contradiction in the literature on how the applied load and the velocity control the wear and frictional behaviour of metals. Gultekin et al. (2010) and Uyyuru, Surappa and Brusethaug (2007) reported that increase the velocity reduces the friction coefficient which in agreements with the current results.

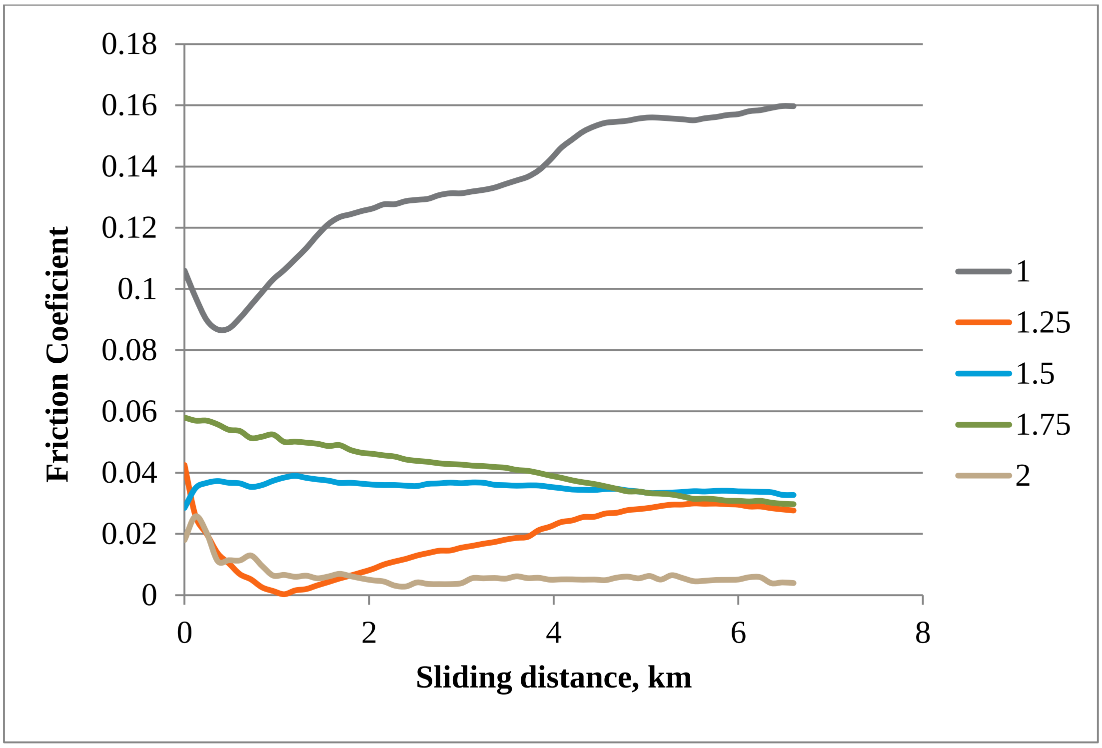


Figure 4. 29 Friction coefficient against sliding distance at different velocities under 40% synthetic oil blended with canola oil lubricant conditions

4.4.4 Frictional behaviour of Mild steel under lubricant condition of (60% synthetic & 40% Canola)

The friction coefficient of the mild steel under the lubricant of 60 % synthetic oil mixed with 40 % canola oil is presented in Figures 4.30 and 4.31 under different applied loads, and sliding velocities. From bother figures, it can be seems that the increase in the applied load reduces the friction coefficient which is supported by the fundamental law of the friction which is given by Archard (1957) and lately confirmed and supported by many researchers such as (Alonso Gil & Igual Muñoz 2011; Kondratiuk & Kuhn 2011; Walker, Kamps & Wood 2013). The increase in the sliding velocity exhibits an increase in the friction coefficient which is in agreements with the literature and previous sections since the increase in the velocity increases the shear in the interface at the same applied load. This has been explained in detail in the previous section.

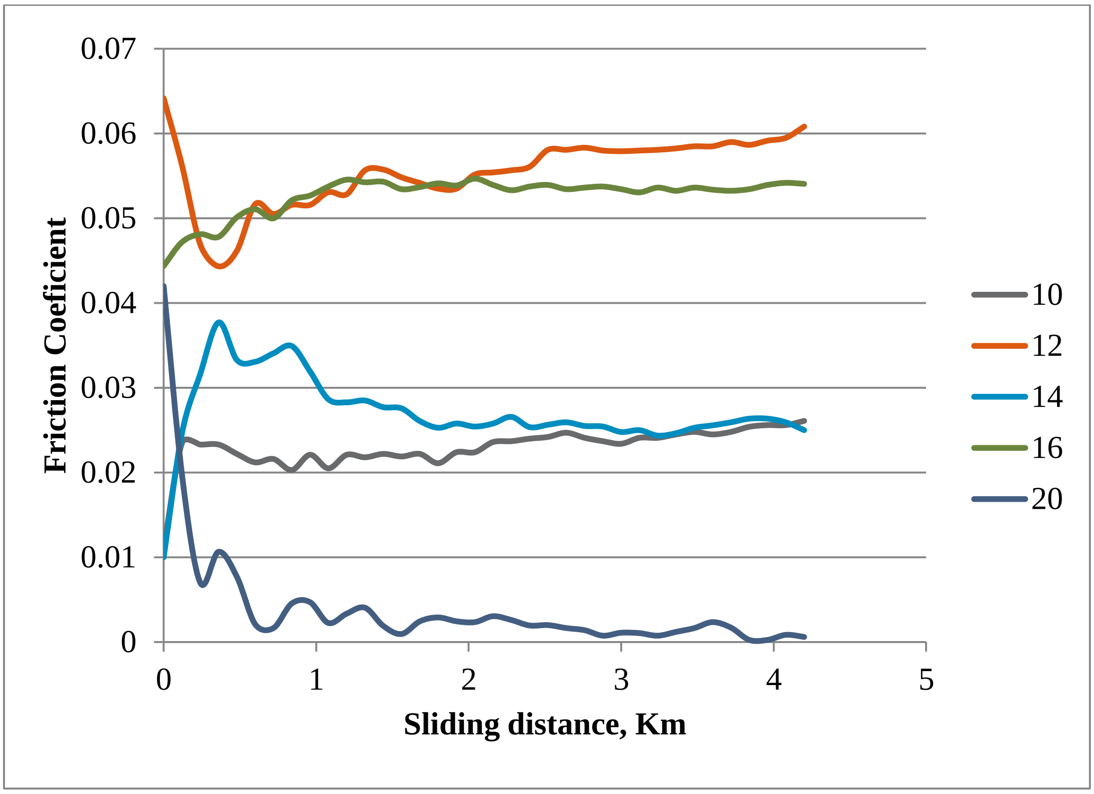


Figure 4. 30 Friction coefficient against sliding distance at different applied loads under 60 % synthetic oil blended with canola oil lubricant conditions

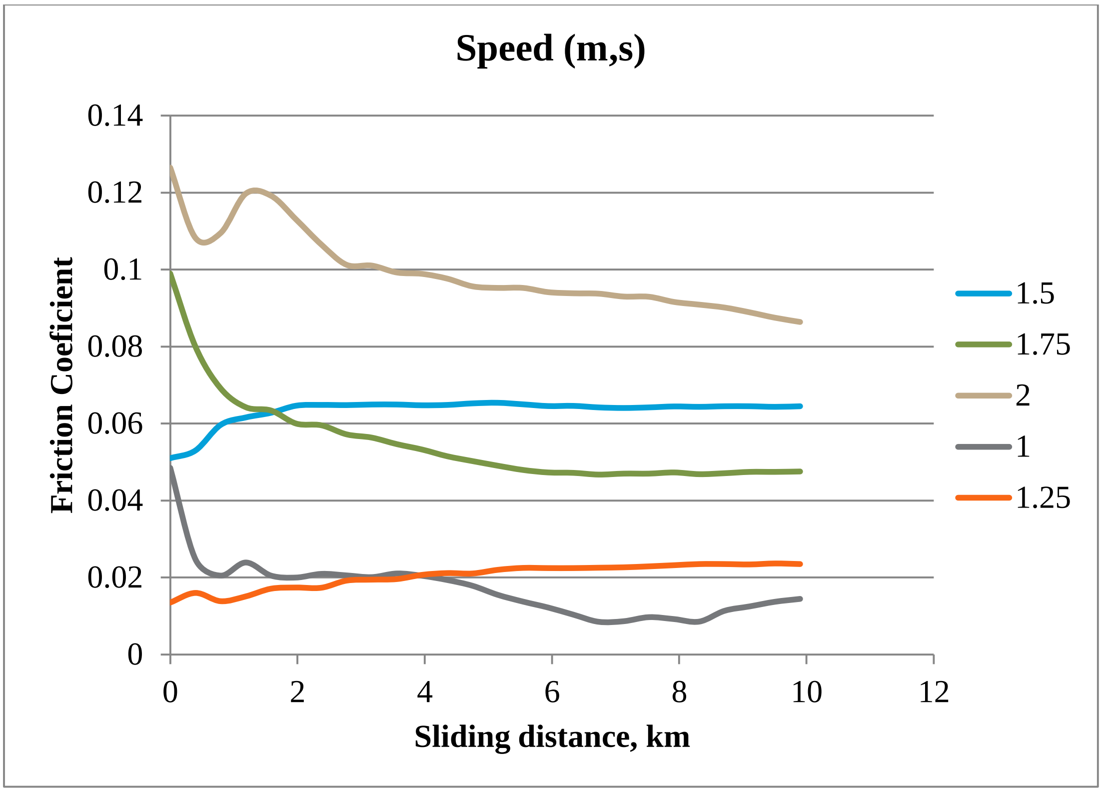


Figure 4. 31 Friction coefficient against sliding distance at different velocities under 60% synthetic oil blended with canola oil lubricant conditions

4.4.5 Frictional behaviour of Mild steel under lubricant condition of (80% synthetic & 20% Canola)

The friction coefficient of the mild steel under the lubricant of 80% synthetic oil mixed with 20 % canola oil blend is presented in Figures 4.32 and 4.33 under different applied loads, and sliding velocities, respectively. Based on the trends in Figure 4.32, the increase in the applied load reduces the friction coefficient and a steady state for all the trends can be seen under different applied loads. This is in agreement with the previous sections under different blends lubricant and as mentioned previously the results are in agreements with the published works such as (Alonso Gil & Igual Muñoz 2011; Kondratiuk & Kuhn 2011; Walker, Kamps & Wood 2013).

For the influence of the sliding velocity on the friction coefficient of the milds steel under the 80 % syntactic blend, there is no remarkable effect of the sliding velocity on the friction coefficient and this is mainly due to the high content of the synthetic oil in the blend. From the viscosity data presented in Figures 4.1 and 4.2, this blend which contains 80% synthetic has the highest viscosity among the other blends. The high viscosity protects the surface of the mild steel which resulted in low friction coefficient and there will be no effect of the sliding velocity on the friction coefficient. This has been explained with the roles of the lubricant and additives by (Johansson, Devlin & Prakash 2014; McKeen 2016). As stated by McKeen (2016), the additives in the synthetic lubricant plays the main role in controlling the wear and the frictional behaviour of metals in which the additives will control "*abrasion resistance improvers, rust inhibitor, corrosion inhibitor, thickeners, film-forming agent, deaerators, degassing agent, dispersant*".

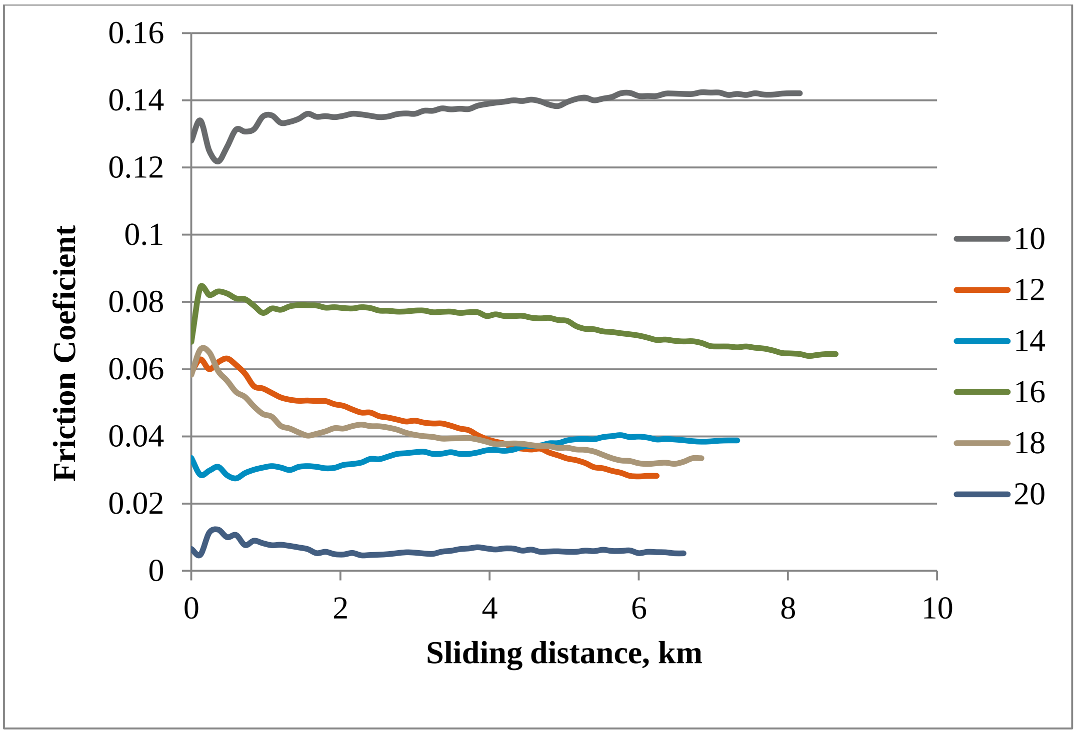


Figure 4. 32 Friction coefficient against sliding distance at different applied loads under 80 % synthetic oil blended with canola oil lubricant conditions

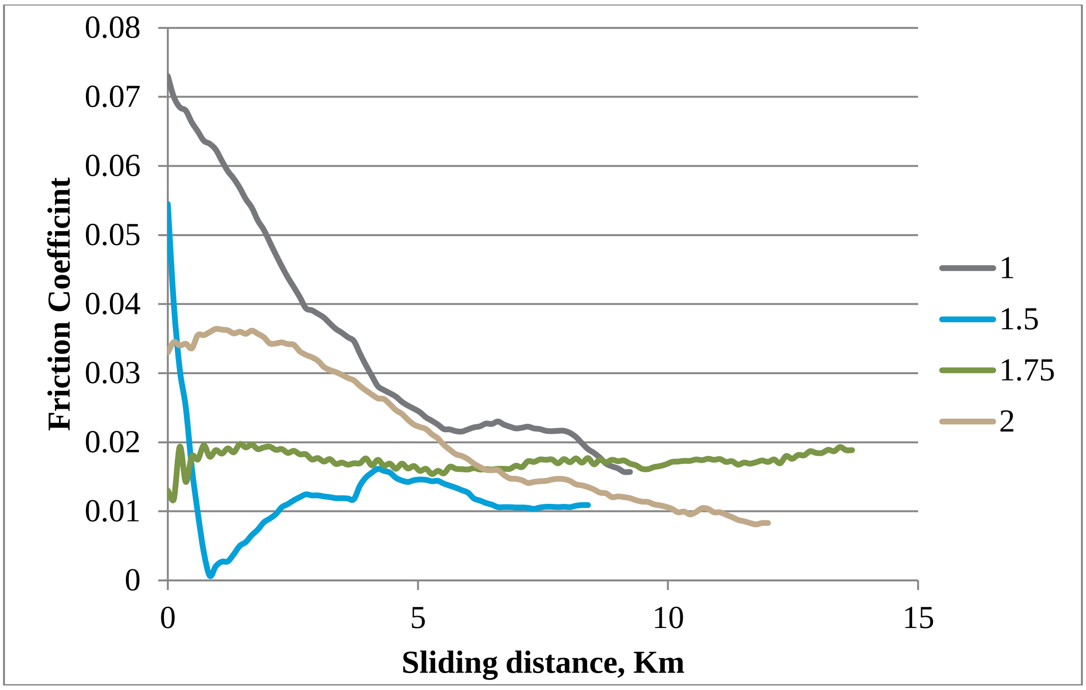


Figure 4. 33 Friction coefficient against sliding distance at different velocities under 80% synthetic oil blended with canola oil lubricant conditions

4.4.6 Effect of synthetic oil on frictional behaviour of mild steel under different blends lubricant conditions

To identify the optimum blend in term of frictional performance, the friction coefficient against sliding distance is presented in Figure 4.34 for all the types of blends at the sliding velocity of 2 m/s and applied load of 10 N. One can see that the difference in the friction coefficient is obvious. Pure vegetable oils shows high friction coefficient compared to its blinds especially at high percentage of synthetic oil and this is mainly due to the fact that given in the viscosity results since the synthetic oil given high viscosity compared to the vegetable oil. The high viscosity ensure the separation of the rubbed surfaces which results in low friction coefficient. On the other hand, mixing the syntactic oil with the at intermediate ratio of about 20 % to 40 % syntactic oil mixed with canola introduces the lowest friction coefficient.

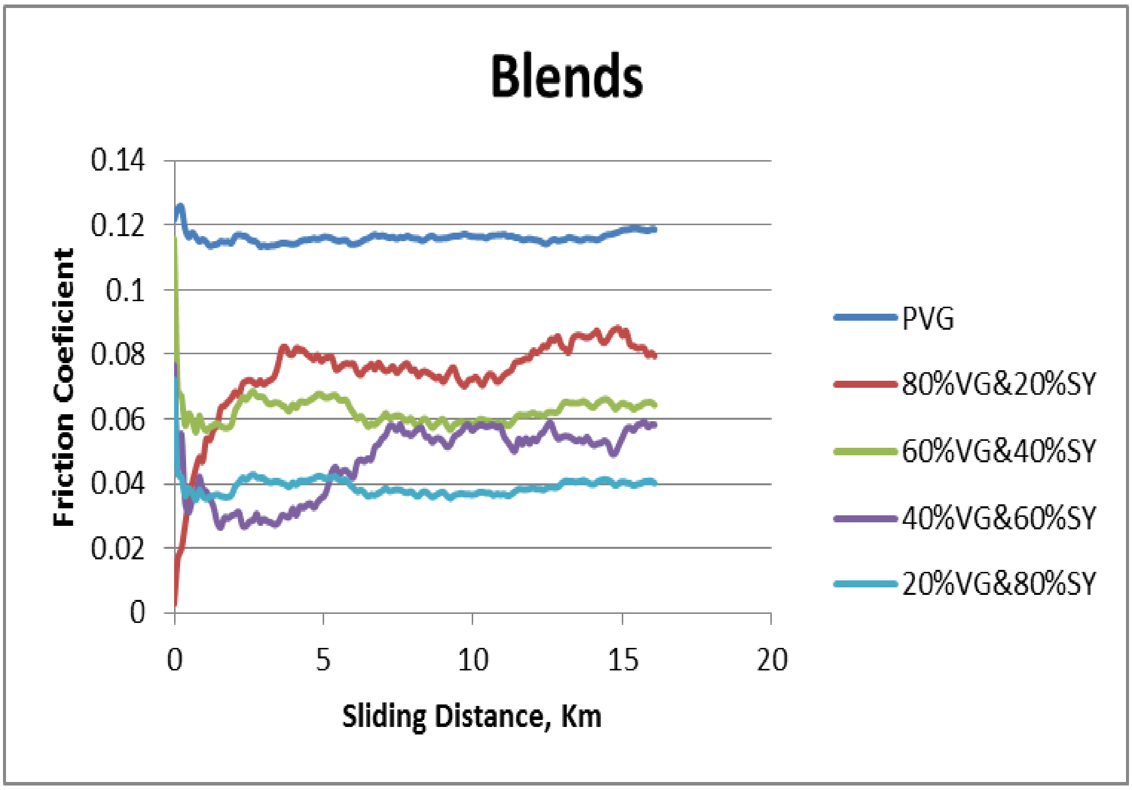


Figure 4. 34 Friction coefficient against sliding distance at different blends lubricant conditions at 10 N applied load with 2 m/s sliding velocity.

4.5 SCANNING ELECTRON MICROSCOPY OBSERVATIONS

The surface morphology of the mild steel worn surfaces are displayed in Figure 4.35 a-e which has been tested under different lubricants at 20 N applied load, 10 km sliding distance, and 2 m/s sliding velocity. The figure shows different damage features and wear behaviour which are as follows:

- Under the pure canola oil lubricant condition (Figure 4.35a) , a smooth surface appears which represent a pure adhesive wear. This indicates the low materials removal from the mild steel surface which support the results given in Figure 4. 23. However, in term of frictional performance, it seems there is a continue rubbing process against the stainless steel with the presence of the low viscosity oil (pure canola). The low viscosity oil can assist to reduce the heat in the interface and wash out the debris, (Araruna Jr, Portes, Soares, Silva, Sthel, Schramm, Tibana &Vargas 2004; Tang, Xiong, Wan, Guo, Zhou, Huang &Zhong 2015).

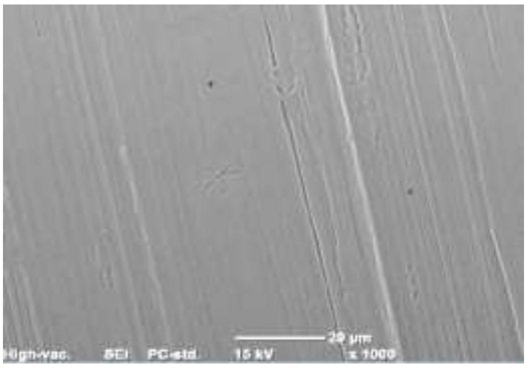
- Figure 4.35 b shows a sign of abrasive nature on the surface of the mild steel when 20% synthetic oil blended with 80% canola used as lubricant. This may support the idea of that the increase in the viscosity, which resulted from the addition of the syntactic oil, allows the lubricant to carry the debris and then enter the interface. In other words, the adhesive wear transfer into abrasive.
- Figure 4.35 c shows further abrasive nature to the one appeared in Figure 4.35 b. Since the worn surface at this figure was generated when higher viscosity of lubricant used, it confirms the concept of that high viscosity carries the debris and then convert the adhesive wear into abrasive resulting in high removal of materials (Figure 4.23).
- Figure 4.35 d and e show sever abrasive nature and deterioration on the surface of the mild steel and it believes to be due to the three abrasive nature

Despite of the above thoughts and concepts, it is necessary to conduct further study on the surface analysis in term of the lubricant coating, roughness profile, modifications on the counterface during the testing, analyse the debris generated from the interface, and the impact of the interface temperature.

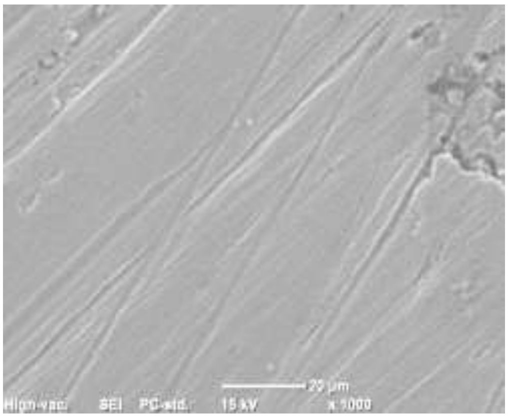
In the literature, the works on the vegetable oil as lubricant are increasing. There are different techniques have been used to understand the tribological performance of the vegetable oil in term of viscosity, wear and friction impact on rubbed surfaces. The viscosity of Soybean oil (SYO), sunflower oil (SO) and castor oil (CO) has been investigated considering different temperatures by Quinchia, Delgado, Valencia, FrancoGallegos (2010). In that work, the viscosity of the oils found to be 250 µPa s, 290 µPa s and 320 µPa s for SYO, SO, and CO. it should be mentioned here that those oils have been modified with the addition of the 4% EVA stabiliser. The current study shows that the range of the viscosity of canola oil at the same range of temperature (25 ºC), is about 80 µPa s which is much lower than the published studied. However, similar range of the current viscosity is reported by Quinchia et al. (2014) when pure

Soybean oil (SYO), sunflower oil (SO) and castor oil (CO) used. It seems the addition of the 4% EVA significantly increases the viscosity of the vegetable oil which can be recommended for the canola oil as well. Despite of that, the current study is also in agreements with the published work by the same authors, Quinchia, Delgado, Franco, SpikesGallegos (2012).

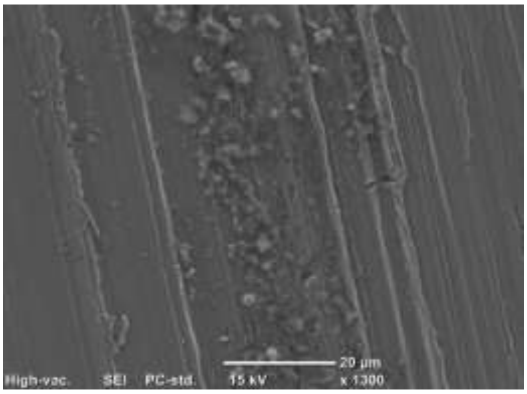
With regards to the wear and frictional influences of the vegetable oil on metal-metal contact, there are few works have been attempted to study the frictional behaviour of metals under vegetable lubricant conditions. Martín-Alfonso and Valencia (2015) studied the frictional performance of metals under the lubricant conditions of leogels based on conventional (SO) and high-oleic sunflower (HOSO) vegetable oils and ethylene–vinyl acetate copolymer (EVA) for lubricant applications. In that work, the friction coefficient range was in about 0.12 ± 0.4. In my current results the friction coefficient was in range of 0.03- 0.12. The main reason for my low friction coefficient is the low viscosity of canola oil compared to the modified SO and HOSO oils. The usage of canola oil as lubricant can be more beneficial than the SO and HOSO for the application when low frication coefficient required especially in machining, bearing and slides. Epoxidized soybean oil (ESBO) introduced similar values of friction coefficient as reported by (Sharma, Adhvaryu & Erhan 2009). Zulkifli, Azman, Kalam, Masjuki, YunusGulzar (2016) generated a new vegetable oil as lubricfant which was extracted from oil palm. The oils are trimethylolpropane (TMP) and pentaerythritol ester (PE). Those oils in pure condition exhibited very high friction coefficient which reached at about 0.4 in certain conditions. However, the authors modified the oils with the addition of synthetic additives such as EVA resulted in a low friction coefficient. The current results of friction is very comparable and competitive to the ones reported on the modified trimethylolpropane (TMP) and pentaerythritol (TMP).



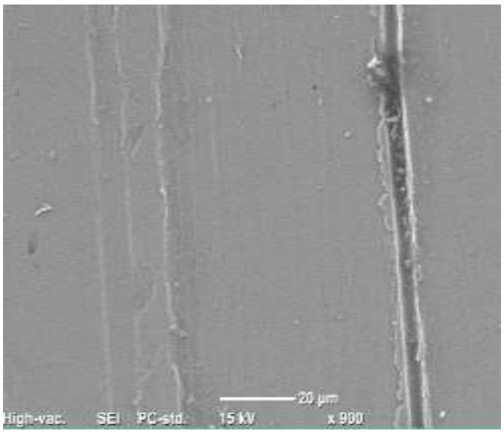
a) 100% canola oil 20N applied load, 10 km sliding distance, and 2 m/s sliding velocity.



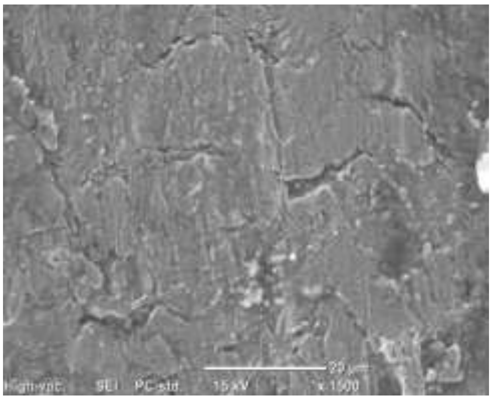
b) 20% syntactic oil, 20N applied load, 10 km sliding distance, and 2 m/s sliding velocity.



c) 40 % syntactic oil, 20N applied load , 10 km sliding distance, and 2 m/s sliding velocity.



d) 60% syntactic oil, 20N applied load , 10 km sliding distance, and 2 m/s sliding velocity.



e) 80% Syntactic oil, 20N applied load , 10 km sliding distance, and 2 m/s sliding velocity.

Figure 4. 35 micrographs of the mild steel worn surface after testing at different types of blends.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The main goal of this project is to study the viscosity of the canola oil and its blends with different ratio of fully synthetic oil and investigate the influence of those developed blends on wear and frictional performance of mild steel rubbed against stainless steel counterface. The results revealed that the canola oil has very low viscosity compared to the ones already investigated in the literate such as soy, palm, and cotton. However, this can be beneficial for the canola oil for certain applications in which low viscosity is required such as bearings, bushes and slides. Some specific findings of this work can be found in the following points:

1. The viscosity of the canola oil and its blends with synthetic oil is significantly dependant on the environmental temperature. The increase in the temperature reduces viscosity of the lubricant and this is applicable for the prepared blends.
2. Blending the canola oil with synthetic oil increases the viscosity of the lubricant which in some conditions improved the properties of the lubricant. At high viscosity, the lubricant is able to spreads the two rubbed surfaces with lubricant film. However, the high viscosity oil can carry the worn debris and those debris can inter the interface and created three body abrasion resulting in high removal of materials.
3. For the tribological results, the operating parameters have played the main role in controlling the wear and frictional behaviour of the mild steel under all the types of blends. Increase the sliding distances increase the weight loss of the mild steel at all the operating conditions and blends. On the other hand, specific wear rate exhibited steady state after about 5 km sliding distance for most of the operating conditions. The frictional behaviour of the mils steel was

dependant on the applied load and villosity rather than the sliding distance since it reached the steady state after about 0.25 km for all the conditions.

4. With regards to the influence of the blends on the wear of the mild steel, there is no remarkable influence of the mixing ratio of canola and syntactic oil since the pure canola oil exhibited competitive wear performance among other blends. Despite of that intermediate mixing ratio (40% - 60% synthetic oil mixed with 60% - 40% canola) produced slightly low specific wear rate among others.
5. Canola oil generates the highest friction for the mild steel compared to the other blends which was due to the low viscosity of the canola. Despite of this, the different in the friction coefficient value was not that high compared to the ones reported in the literature for the soya, palm and cotton seeds oils. In other words, the canola oil can be good alternative candidate compared to the soya, palm and cotton seeds oils
6. Vegetable oil continues to show great promise in its efficacy in the use as a tribological compound s. The use of this alternative exploits the structures of biofuels and how this closely knit structure can be used to be just as good an alternative to fossil fuels. The use of biodiesel in the field of tribology means great promise since these fuels are a form of renewable sources which can be exploited without worries of depletion.

5.2 RECOMMENDATIONS

There were some limitation while I am conducting the experiments and analysing the results and those are mainly the time limit of the project, the available chemical equipment. Therefore, there are some recommendations need to be considered for the future works which are as follows:

1. Measurement of film thickness is significant to identify the damages on the surfaces and introduces new understanding on the impact of the viscosity on the wear and frictional performance of metals.
2. Chemical reaction of the prepared blends with the surface of the mild steel should be understood which can assist to identify the reasons for the wear behaviour of the melts
3. There are more works need to be done in term of the oil characteristics such as the flashpoint, and combustion properties to ensure the safety of the usage of this oil under high temperatures

REFERENCES

Aachary, AA, Thiyam-Hollander, U & Eskin, MN 2014, 'Canola/Rapeseed Proteins and Peptides', *Applied Food Protein Chemistry*, pp. 193-218,

Agunsoye, J, Talabi, S, Awe, O & Kelechi, H 2013, 'Mechanical properties and tribological behaviour of recycled polyethylene/cow bone particulate composite', *Journal of Materials Science Research*, vol. 2, no. 2, p. p41,

Alidokht, SA, Abdollah-zadeh, A & Assadi, H 2013, 'Effect of applied load on the dry sliding wear behaviour and the subsurface deformation on hybrid metal matrix composite', *Wear*, vol. 305, no. 1–2, pp. 291-298, <http://www.sciencedirect.com/science/article/pii/S0043164812003869>

Alonso Gil, R & Igual Muñoz, A 2011, 'Influence of the sliding velocity and the applied potential on the corrosion and wear behavior of HC CoCrMo biomedical alloy in simulated body fluids', *Journal of the Mechanical Behavior of Biomedical Materials*, vol. 4, no. 8, pp. 2090-2102, <http://www.sciencedirect.com/science/article/pii/S1751616111001950>

Alotaibi, J & Yousif, B 2016, 'Biolubricants and the Potential of Waste Cooking Oil', in *Ecotribology*, Springer, pp. 125-143.

Araruna Jr, JT, Portes, VLO, Soares, APL, Silva, MG, Sthel, MS, Schramm, DU, Tibana, S & Vargas, H 2004, 'Oil spills debris clean up by thermal desorption', *Journal of Hazardous Materials,* vol. 110, no. 1–3, pp. 161-171, <http://www.sciencedirect.com/science/article/pii/S0304389404001426>

Archard, JF 1957, 'Elastic Deformation and the Laws of Friction', *Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, vol.

243, no. 1233, pp. 190-205, <http://rspa.royalsocietypublishing.org/royprsa/243/1233/190.full.pdf>

Bahadur, S 2000, 'The development of transfer layers and their role in polymer tribology', *Wear*, vol. 245, no. 1, pp. 92-99,

Bart, JC, Cavallaro, S & Gucciardi, E 2012, *Biolubricants: Science and technology*, Elsevier,

Bassam, NE 2013, *Energy plant species: their use and impact on environment and development*, Routledge,

Bayer, RG 2004, *Engineering Design for Wear, Second Edition, Revised and Expanded*, CRC Press, https://books.google.com.au/books?id=lrruQKJbZIoC>

Bhushan, B 2013a, *Introduction to Tribology*, Wiley, https://books.google.com.au/books?id=DJDv5jVwC2UC>

Bhushan, B 2013b, *Principles and Applications of Tribology*, Wiley, https://books.google.com.au/books?id=jbqkjApF2FQC>

Blau, PJ 2006, 'On the nature of running-in', *Tribology International*, vol. 38, no. 11, pp. 1007-1012,

Bowden, F & Freitag, E 1958, 'The friction of solids at very high speeds. I. Metal on metal; II. Metal on diamond', in *Proceedings of Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, The Royal Society, pp. 350-367.

Carnes, K 2005, 'The ten greatest events in tribology history', *Tribology & Lubrication Technology*, vol. 61, no. 6, p. 38, Chin, CW & Yousif, BF 2009, 'Potential of kenaf fibres as reinforcement for tribological applications', *Wear*, vol. 267, no. 9–10, pp. 1550-1557, <http://www.sciencedirect.com/science/article/pii/S0043164809004128>

Chryssolouris, G 2013, *Manufacturing systems: theory and practice*, Springer Science & Business Media,

Clark, JGD & Thompson, MW 1954, 'The Groove and Splinter Technique of working antler in Upper Palaeolithic and Mesolithic Europe', *Proceedings of the Prehistoric Society (New Series)*, vol. 19, no. 02, pp. 148-160,

Czichos, H 2009, *Tribology: a systems approach to the science and technology of friction, lubrication, and wear: a systems approach to the science and technology of friction, lubrication, and wear*, Elsevier,

Danilov, A 2015, 'Progress in research on fuel additives (review)', *Petroleum Chemistry*, vol. 55, no. 3, pp. 169-179,

Day, L 2013, 'Proteins from land plants–potential resources for human nutrition and food security', *Trends in Food Science & Technology*, vol. 32, no. 1, pp. 25-42,

de Marchi, JA 1998, 'Modeling of dynamic friction, impact backlash and elastic compliance nonlinearities in machine tools, with applications to asymmetric viscous and kinetic friction identification', Rensselaer Polytechnic Institute.

Dowson, D & Dowson, D 1979, *History of tribology*, Longman London,

El-Adly, RA & Ismail, EA 2011, *Lubricating Greases Based on Fatty By-Products and Jojoba Constituents*, INTECH Open Access Publisher,

Governo, J & Zacharias, H 2001, 'Characterization of the Generation, Handling and Treatment of Spent Fat, Oil, and Grease (FOG) from Georgia’s Food Service Industry', Gultekin, D, Uysal, M, Aslan, S, Alaf, M, Guler, MO & Akbulut, H 2010, 'The effects of applied load on the coefficient of friction in Cu-MMC brake pad/Al-SiCp MMC brake disc system', *Wear*, vol. 270, no. 1–2, pp. 73-82, <http://www.sciencedirect.com/science/article/pii/S0043164810003108>

Haessig, DA & Friedland, B 1991, 'On the modeling and simulation of friction', *Journal of Dynamic Systems, Measurement, and Control*, vol. 113, no. 3, pp. 354-362,

Hirani, H 'Tribology deals with design of fluid containment systems like seals and gasket, Lubrication of surfaces in relative motion to achieve reduced friction and wear. The structure of the bearing and the nature of fluid flow determine the loads that can be supported. Modeling systems as hydrostatic squeeze film and Elasto-hydrodynamic lubrication will be studied as infinite and later finite structures. Gas (air) lubricated and rolling contact type motions with deformation at contact will be studied as special systems',

Johansson, JE, Devlin, MT & Prakash, B 2014, 'Lubricant additives for improved pitting performance through a reduction of thin-film friction', *Tribology International*, vol. 80, pp. 122-130, <http://www.sciencedirect.com/science/article/pii/S0301679X14002552>

Kahn, H, Ernst, F & Heuer, AH 2016, 'Increasing the coefficient of sliding friction of NiCr at low loads by interstitial surface hardening', *Wear*, vol. 346–347, pp. 1-5, <http://www.sciencedirect.com/science/article/pii/S0043164815004500>

Kondratiuk, J & Kuhn, P 2011, 'Tribological investigation on friction and wear behaviour of coatings for hot sheet metal forming', *Wear*, vol. 270, no. 11–12, pp. 839-849, <http://www.sciencedirect.com/science/article/pii/S0043164811000639>

Lin, C-Y 2013, 'Strategies for promoting biodiesel use in marine vessels', *Marine Policy*, vol. 40, pp. 84-90, Lindroos, M, Valtonen, K, Kemppainen, A, Laukkanen, A, Holmberg, K & Kuokkala, V-T 2015, 'Wear behavior and work hardening of high strength steels in high stress abrasion', *Wear*, vol. 322–323, pp. 32-40, <http://www.sciencedirect.com/science/article/pii/S0043164814003238>

Lubrecht, AA & Dalmaz, G 2004, *Transient Processes in Tribology: Proceedings of the 30th Leeds-Lyon Symposium on Tribiology*, Elsevier Science, https://books.google.com.au/books?id=BIEtt70piZ4C>

Mansouri, S & Wong, V 2005, 'Effects of piston design parameters on piston secondary motion and skirt-liner friction', *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, vol. 219, no. 6, pp. 435-449,

Martín-Alfonso, JE & Valencia, C 2015, 'Tribological, rheological, and microstructural characterization of oleogels based on EVA copolymer and vegetables oils for lubricant applications', *Tribology International*, vol. 90, pp. 426-434, <http://www.sciencedirect.com/science/article/pii/S0301679X15002030>

Mat Tahir, NA, Abdollah, MFB, Hasan, R & Amiruddin, H 2016, 'The effect of sliding distance at different temperatures on the tribological properties of a palm kernel activated carbon–epoxy composite', *Tribology International*, vol. 94, pp. 352-359, <http://www.sciencedirect.com/science/article/pii/S0301679X15004508>

McKeen, LW 2016, '7 - Additives', in LW McKeen (ed.), *Fluorinated Coatings and Finishes Handbook (Second Edition)*, William Andrew Publishing, Oxford, pp. 119-127.

Mobarak, H, Mohamad, EN, Masjuki, H, Kalam, M, Al Mahmud, K, Habibullah, M & Ashraful, A 2014, 'The prospects of biolubricants as alternatives in automotive applications', *Renewable and Sustainable Energy Reviews*, vol. 33, pp. 34-43, Moka, S, Pande, M, Rani, M, Gakhar, R, Sharma, M, Rani, J & Bhaskarwar, AN 2014, 'Alternative fuels: an overview of current trends and scope for future', *Renewable and Sustainable Energy Reviews*, vol. 32, pp. 697-712,

Moses, CA & Roets, PN 2009, 'Properties, characteristics, and combustion performance of Sasol fully synthetic jet fuel', *Journal of Engineering for Gas Turbines and Power*, vol. 131, no. 4, p. 041502,

Nagendramma, P & Kaul, S 2012, 'Development of ecofriendly/biodegradable lubricants: An overview', *Renewable and Sustainable Energy Reviews*, vol. 16, no. 1, pp. 764-774,

Norrby, T & Kopp, M 2000, 'Environmentally adapted lubricants in Swedish forest industry-a critical review and case study', *Industrial Lubrication and Tribology*, vol. 52, no. 3, pp. 116-125,

Przybylski, R, Mag, T, Eskin, N & McDonald, B 2005, 'Canola oil', *Bailey's industrial oil and fat products*,

Quinchia, LA, Delgado, MA, Valencia, C, Franco, JM & Gallegos, C 2010, 'Viscosity modification of different vegetable oils with EVA copolymer for lubricant applications', *Industrial Crops and Products*, vol. 32, no. 3, pp. 607-612, <http://www.sciencedirect.com/science/article/pii/S0926669010001895>

Quinchia, LA, Delgado, MA, Franco, JM, Spikes, HA & Gallegos, C 2012, 'Low-temperature flow behaviour of vegetable oil-based lubricants', *Industrial Crops and Products*, vol. 37, no. 1, pp. 383-388, <http://www.sciencedirect.com/science/article/pii/S0926669011004845>

Quinchia, LA, Delgado, MA, Reddyhoff, T, Gallegos, C & Spikes, HA 2014, 'Tribological studies of potential vegetable oil-based lubricants containing environmentally friendly viscosity modifiers', *Tribology International*, vol. 69, pp. 110-117, <http://www.sciencedirect.com/science/article/pii/S0301679X13002971>

Rafiq, M, Lv, YZ, Zhou, Y, Ma, KB, Wang, W, Li, CR & Wang, Q 2015, 'Use of vegetable oils as transformer oils – a review', *Renewable and Sustainable Energy Reviews*, vol. 52, pp. 308-324, <http://www.sciencedirect.com/science/article/pii/S1364032115006796>

Ramadhas, A, Jayaraj, S & Muraleedharan, C 2004, 'Use of vegetable oils as IC engine fuels—a review', *Renewable energy*, vol. 29, no. 5, pp. 727-742,

Raposo Jr, JL, Oliveira, SR, Neto, JAG, Nobrega, JA & Jones, BT 2011, 'Determination of silicon in lubricant oil by high-resolution continuum source flame atomic absorption spectrometry using least-square background correction and internal standardization', *Analytical Letters*, vol. 44, no. 12, pp. 2150-2161,

Reti, L 1968, 'The Two Unpublished Manuscripts of Leonardo Da Vinci in the Biblioteca Nacional of Madrid-I', *The Burlington Magazine*, pp. 10-12,

Rowe, RC, Shesjey, PJ & Owen, SC 2005, *Pharmaceutical Excipients 5: Single-User Version*, McGraw-Hill Medical Publishing Division,

Ruiz-Andres, M, Conde, A, de Damborenea, J & Garcia, I 2015, 'Friction and wear behaviour of dual phase steels in discontinuous sliding contact conditions as a function of sliding speed and contact frequency', *Tribology International*, vol. 90, pp. 32-42, <http://www.sciencedirect.com/science/article/pii/S0301679X15001395>

Scherge, M, Linsler, D & Schlarb, T 2015, 'The running-in corridor of lubricated metal–metal contacts', *Wear*, vol. 342–343, pp. 60-64, <http://www.sciencedirect.com/science/article/pii/S0043164815003865>

Sharma, BK, Adhvaryu, A & Erhan, SZ 2009, 'Friction and wear behavior of thioether hydroxy vegetable oil', *Tribology International*, vol. 42, no. 2, pp. 353-358, <http://www.sciencedirect.com/science/article/pii/S0301679X08001606>

Shukla, A & Srivastava, VK 2013, 'Vegetable oil, biodiesel-An unconventional and environmental friendly source of liquid fuel', *The Indian Research Journal of Genetics and Biotechnology*, vol. 5, no. 2, pp. 88-97,

Stachowiak, G & Batchelor, AW 2013, *Engineering tribology*, Butterworth-Heinemann,

Tang, L, Xiong, J, Wan, W, Guo, Z, Zhou, W, Huang, S & Zhong, H 2015, 'The effect of fluid viscosity on the erosion wear behavior of Ti(C,N)-based cermets', *Ceramics International*, vol. 41, no. 3, Part A, pp. 3420-3426, <http://www.sciencedirect.com/science/article/pii/S0272884214016939>

Trent, E 1988, 'Metal cutting and the tribology of seizure: I seizure in metal cutting', *Wear*, vol. 128, no. 1, pp. 29-45,

Uyyuru, RK, Surappa, MK & Brusethaug, S 2007, 'Tribological behavior of Al-Si-SiCp composites/automobile brake pad system under dry sliding conditions', *Tribology International*, vol. 40, no. 2 SPEC. ISS., pp. 365-373, <http://www.scopus.com/inward/record.url?eid=2-s2.0-33748942946&partnerID=40&md5=be6fdb8ddf2fec3e0024032d3073e2f4>

Vasyliev, GS 2015, 'The influence of flow rate on corrosion of mild steel in hot tap water', *Corrosion Science*, vol. 98, pp. 33-39, <http://www.sciencedirect.com/science/article/pii/S0010938X15002024>

Walker, JC, Kamps, TJ & Wood, RJK 2013, 'The influence of start–stop transient velocity on the friction and wear behaviour of a hyper-eutectic Al–Si automotive alloy', *Wear*, vol. 306, no. 1–2, pp. 209-218, <http://www.sciencedirect.com/science/article/pii/S0043164812003456>

Williams, J 1994, *Engineering tribology*, Cambridge University Press,

Wimmer, MA, Laurent, MP, Mathew, MT, Nagelli, C, Liao, Y, Marks, LD, Jacobs, JJ & Fischer, A 2015, 'The effect of contact load on CoCrMo wear and the formation and retention of tribofilms', *Wear*, vol. 332–333, pp. 643-649, viewed 2015/6//, <http://www.sciencedirect.com/science/article/pii/S0043164815001222>

Yousif, BF & El-Tayeb, NSM 2008, 'Wear and friction characteristics of CGRP composite under wet contact condition using two different test techniques', *Wear*, vol. 265, no. 5-6, pp. 856-864, <http://www.sciencedirect.com/science/article/B6V5B-4S02T6N-2/2/1ac70b41f1d22ec46452b1f5b924cf30>

Zappi, M, Hernandez, R, Sparks, D, Horne, J, Brough, M, Arora, S & Motsenbocker, WD 2003, 'A review of the engineering aspects of the biodiesel industry', *MSU E-TECH Laboratory Report ET-03-003*,

Zheng, X, Zhang, S, Li, W, Gong, M & Yin, L 2015, 'Experimental and theoretical studies of two imidazolium-based ionic liquids as inhibitors for mild steel in sulfuric acid solution', *Corrosion Science*, vol. 95, pp. 168-179, <http://www.sciencedirect.com/science/article/pii/S0010938X15001390>

Zulkifli, NWM, Azman, SSN, Kalam, MA, Masjuki, HH, Yunus, R & Gulzar, M 2016, 'Lubricity of bio-based lubricant derived from different chemically modified fatty acid methyl ester', *Tribology International*, vol. 93, Part B, pp. 555-562, <http://www.sciencedirect.com/science/article/pii/S0301679X15001140>

APPENDIX A: PROJECT SPECIFICATION

Topic	study on tribological performance of mild steel under bio lubricant conditions
Project Aim	• To investigate the impact of vegetable oil on the tribological performance of mild steel under different tribological loading conditions, i.e. applied loads, speeds, oil temperatures. • Examine the worn surfaces features using roughness profile and scanning electron microscopy.
Sponsorship	Nil

Programme

- Build the literature and identify the recent issues in the area
- Prepare the vegetable oil.
- Prepare the metal sample for the tribological test
- Conduct the experiments with the consideration of different applied loads at constant speed
- Analysis the results.
- Investigate e the surface damage using SEM
- Analysis the data and give the recommendations

APPENDIX B: RESOURCE REQUIREMENT:

Basically the experiments required different resources to prepare out the experiments and produce the final results which would be further tested.

Viscometer:

A viscometer (or, viscometer) is using to measure the viscosity of a blend or a fluid. For blends viscosities that vary with condition of flow, a rheometer implement is used. Viscometer limited to measure one flow condition only. Generally, either a spindle moves through blend or blend in a stationary condition, or a spindle is stationary and the b moves. Motion of a fluid by an object (spindle) causing the drag and the viscosity is measured. Small Reynolds number value must be considered for a laminar flow. A suitable viscometer is available at USQ laboratory.

Polishing machine

Also known as a buffing machine, it has a rotating surface that can smooth rough surfaces in contact.

Tribology machine

I would be using the tribology machine available at USQ laboratory, described in section 3.3.

SEM

Scanning electron microscope (SEM) is an instrument that produce an image of the surface damages in a sample that need to be. An SEM machine is also available at the USQ laboratory, which I intend to use.

Roughness test

Roughness is an important parameter when trying to find out whether a surface is suitable for a certain purpose. Rough surfaces often wear out more quickly than smoother surfaces. Rougher surfaces are normally more vulnerable to corrosion and cracks, but they can also aid adhesion. The roughness tester is used to quickly and accurately determine the surface roughness of a material, and is available at USQ laboratory.

PPE (Personal protective equipment):

USQ provides PPE gears Normally these gears include: safety chemicals gloves, disposable surgical gloves, additional gloves, dust masks, chemical mask, and safety glasses.

Project timeline:

Enrolment: ENG4111– S1, 2015;

ENG4112 – S2, 2015.

No.	TASK	DURATION (Approximate. Hours)	START	FINISH
	Project Pre-Planning	15hrs	1 March 2015	30 March 2015
1	Supervisor consultation and Proposal Submission	9	1 March 2015	19 March 2015
2	Build and submit specification of the project & Approval	6	20 March 2015	30 March 2015
	Project Research	365hrs	16 March 2015	17 October 2015
3	Literature reviews	78	16 March 2015	8 April 2015
4	Processes of design and determine (Parameters) for Testing.	41	8 April 2015	14 April 2015
5	Testing types and Specimens Examination.	104	18 April 2015	30 June 2015
6	Results analysis.	72	2 July 2015	29 August 2015
7	More Test (if necessary) & Supervisor Discussion.	15	30 August 2015	28 September 2015
8	Drawing-up Conclusions.	55	2 October 2015	17 October 2015

	Reports	115 hours	19 October 2015	5 November 2015
9	Thesis Outline discussion for the project with Supervisors.	22	19 October 2015	24 October 2015
10	Drafting thesis – every chapter in draft form and presented to Supervisors.	55	25 October 2015	27 October 2015
11	Final Draft of Thesis - to an additional modifications add by Supervisor.	20	28 October 2015	1 November 2015
12	Thesis completion in a required format	18	5 November 2015	16 November 2015

APPENDIX C :RISK ASSESSMENT

University of Southern QueenslandRisk Management PlanDate: 10/08/2015	Faculty/Department: Faculty of Health, Engineering and Sciences	Assessment completed by: Faisal Alajmi	Contact number: 0421283072
What is the task? Performing the wear testing of materials		Location where task is being conducted: Z107.1	
Why is the task being conducted? As a part of my PhD research.			
What are the nominal conditions?			
Personnel Trained personnel	Equipment Wear testing Machine, Balance scale	Environment Air-condition-Room	Other
Briefly explain the procedure for this task (including reference to other procedures) Studying the tribological properties of metals			

Risk register and Analysis

[ALARP = As Low As Reasonably Practicable]

Element or Sub Element / Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? See next page	Is it ALARP ? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?	Is it ALARP? Yes/No	Risk Decision: Accept Transfer

List major steps or tasks in process	Electric shock Eye infection Fire / explosion Physical injury Cut / graze Chemical burn	List all current controls that are already in place or that will be used to undertake the task eg List of Personal Protective Equipment (PPE) Identify types facility, location Existing safety measurers Existing emergency procedures	Consequences	Likelihood	Rating		Additional controls may be required to reduce risk rating eg Greater containment (PC2) Additional PPE – gloves safety glasses Specific induction / training	Consequences	Likelihood	Rating		Treat
Polishing the sample	Abrasive the tip of the figure	Training and wear gloves	2	D	L		NA	2	D	L		Accept

Polishing the same	Debris fly	Training and Wear eye protection	2	D	L		NA	2	D	L		Accept
Measuring the sample weight	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Turn on the wear machine	Electrical shock	Building fitted with RCD. Trained personnel operates machine / Task is supervised. Safe Operating Emergency procedures are in place.	3	E	L	YES	NA	NA	NA	NA	NA	Accept
Placing the sample	Pinching	Sample is manually placed into	1	D	L	YES	NA	NA	NA	NA	NA	Accept

on the machine		position by trained personnel/ Task is supervised. The trained personnel will operate machine. Safe Work Procedures (SWP) have been developed and is readily available. Emergency procedures are in place.										
Heat up the oil	Burn and slippery floor	Use the gloves while heating it up										

		Monitor the temperature Cleaning the floor each test and it necessary use the emergency stop										
Perform the wear testing	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wearing the sample	Debris could fly from the fracture	Wearing eye protection during the wear testing process or Cover should be closed. Safe Work Procedures (SWP) have been developed	2	E	L	YES	NA	NA	NA	NA	NA	Accept

		and is readily available. Emergency procedures are in place.										
Turing off the machine	Electrical shock	Building fitted with RCD. Trained personnel operates machine. Emergency procedures are in place.	3	E	L	YES	NA	NA	NA	NA	NA	Accept
Remove the sample	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Risk Treatment Schedule

Risk No:	Risk (from Risk Register)	Treatment	Person Responsible for Implementation	Timetable for Implementation	Date treatment Completed	Review Effectiveness Effective/Not Effective

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Note: In estimating the level of risk, initially estimate the risk with existing controls and then review risk controls if risk level arising from the risks is not minimal

Table 1 - Consequence

Level	Descriptor	Examples of Description
1	Insignificant	No injuries. Minor delays. Little financial loss. $0 - $4,999*
2	Minor	First aid required. Small spill/gas release easily contained within work area. Nil environmental impact. Financial loss $5,000 - $49,999*
3	Moderate	Medical treatment required. Large spill/gas release contained on campus with help of emergency services. Nil environmental impact. Financial loss $50,000 - $99,999*
4	Major	Extensive or multiple injuries. Hospitalisation required. Permanent severe health effects. Spill/gas release spreads outside campus area. Minimal environmental impact. Financial loss $100,000 - $250,000*
5	Catastrophic	Death of one or more people. Toxic substance or toxic gas release spreads outside campus area. Release of genetically modified organism (s) (GMO). Major environmental impact. Financial loss greater than $250,000*

* Financial loss includes direct costs eg workers compensation and property damage and indirect costs, eg impact of loss of research data and accident investigation time.

TABLE 2 - PROBABILITY

Level	Descriptor	Examples of Description
A	Almost certain	The event is expected to occur in most circumstances. Common or repetitive occurrence at USQ. Constant exposure to hazard. Very high probability of damage.
B	Likely	The event will probably occur in most circumstances. Known history of occurrence at USQ. Frequent exposure to hazard. High probability of damage.
C	Possible	The event could occur at some time. History of single occurrence at USQ. Regular or occasional exposure to hazard. Moderate probability of damage.

D	Unlikely	The event is not likely to occur. Known occurrence in industry. Infrequent exposure to hazard. Low probability of damage.
E	Rare	The event may occur only in exceptional circumstances. No reported occurrence globally. Rare exposure to hazard. Very low probability of damage. Requires multiple system failures.

TABLE 3 – RISK RATING

Probability	Consequence				
	Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
A (Almost certain)	M	H	E	E	E
B (Likely)	M	H	H	E	E
C (Possible)	L	M	H	H	H
D (Unlikely)	L	L	M	M	M
E (Rare)	L	L	L	L	L

TABLE 4 - RECOMMENDED ACTION GUIDE

Abbrev	Action Level	Descriptor
E	Extreme	The proposed task or process activity MUST NOT proceed until the supervisor has reviewed the task or process design and risk controls. They must take steps to firstly eliminate the risk and if this is not possible to introduce measures to control the risk by reducing the level of risk to the lowest level achievable. In the case of an existing hazard that is identified, controls must be put in place immediately.
H	High	Urgent action is required to eliminate or reduce the foreseeable risk arising from the task or process. The supervisor must be made aware of the hazard. However, the supervisor may give special permission for staff to undertake some high risk activities provided that system of work is clearly documented, specific training has been given in the required procedure and an adequate review of the task and risk controls has been undertaken. This includes providing risk controls identified in Legislation, Australian

		Standards, Codes of Practice etc.* A detailed Standard Operating Procedure is required. * and monitoring of its implementation must occur to check the risk level
M	Moderate	Action to eliminate or reduce the risk is required within a specified period. The supervisor should approve all moderate risk task or process activities. A Standard Operating Procedure or Safe Work Method statement is required
L	Low	Manage by routine procedures.

*Note: These regulatory documents identify specific requirements/controls that must be implemented to reduce the risk of an individual undertaking the task to a level that the regulatory body identifies as being acceptable.

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The task should not proceed if the risk rating after the controls are implemented is still either HIGH or EXTREME or if any risk is not As Low As Reasonably Practicable (ALARP).

This Risk Assessment score of Low (L) is only on the condition that all existing and additional controls are in place at the time of the task being conducted.

Assessment completed by:	
Name: Faisal Alajmi	Signature:n
Position: Student	Contact No: 0421283072
Date:10/08/2015	
Supervisor	
Name: Dr. Belal F Yousif	Signature: BFY
Position: Project Supervisor	Contact No: Ext 5331
Date: 10/08/2015	

7 Day Review of Controls:

This Risk Management Plan is to be reviewed not later than seven (7) days after the commencement of the project.

Reviewing Officer	
Name:	Signature:
Position:	Contact No:
Date:	
Supervisor	
Name:	Signature:
Position:	Contact No:
Date:	

12 Monthly Review of this Risk Management Plan:

This Risk Management Plan is to be reviewed every twelve (12) months and whenever a change has been made to the project or workplace.

Reviewing Officer	
Name:	Signature:
Position:	Contact No:
Date:	
Supervisor	
Name:	Signature:
Position:	Contact No:
Date:	

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Guidance Notes for review of Controls and Risk Management Plan.

When monitoring the effectiveness of control measures, it may be helpful to ask the following questions:

• Have the chosen control measures been implemented as planned?

- Are the chosen control measures in place?
- Are the measures being used?
- Are the measures being used correctly?

• Are the chosen control measures working?

- Have any the changes made to manage exposure to the assessed risks resulted in what was intended?
- Has exposure to the assessed risks been eliminated or adequately reduced?

• Are there any new problems?

- Have the implemented control measures introduced any new problems?
- Have the implemented control measures resulted in the worsening of any existing problems?

To answer these questions:

• consult with workers, supervisors and health and safety representatives;
• measure people's exposure (e.g. taking noise measurements in the case of isolation of a noise source);
• consult and monitor incident reports; and
• review safety committee meeting minutes where possible.

Set a date for the review of the risk management process. When reviewing, check if:

• the process that is currently in place is still valid;
• things have changed that could make the operating processes or system outdated;
• technological or other changes have affected the current workplace; and
• a different system should be used altogether