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WEAR STUDY OF COATED/ UNCOATED HIGH SPEED STEEL ON NI-RESIST CAST IRON USING THE COMBINATION OF IONIC LIQUID AND VEGETABLE OIL-BASED LUBRICANT

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Abstract

Mechanical operations such as in the internal combustion engine require robust conditions especially gas engines where it can achieve high combustion temperatures. Materials for pistons rings and cylinder liners are carefully selected to withstand high combustion temperatures and severe wear and friction operation. Surface treatments by applying coats of chromium and DLC to the base material introduce protection to wear, fatigue and corrosion. In this experimental study, high speed steel is simulated as the piston rings and Ni-resist cast iron as the cylinder liner. A tribology study on the effects of bio-lubricant based palm oil combined with 1,3-diethyl imidazolium diethylphosphate on uncoated/coated high speed steel on Ni-resist Cast Iron was carried out using the Reciprocatory Friction Monitoring Machine. The experimental conditions were as follows; normal loads from 10N to 100N, sliding speed was 2000 rpm, with test duration of 30 minutes, approximately 240 meters of sliding distance, room temperature of 30°C and the test temperature of 150°C. The wear and friction curves were plotted and discussed. Used oil samples were checked for ferrous metal debris using the PQ/PQ90A dual-coil magnetometer.

Keywords: *Palm Oil,Ionic Liquid, High Speed Steel, Ni-resist Cast Iron, Tribology,*

1. Introduction

Mineral oils have been dominated the lubricant market since its introduction. But due to growing worldwide interest in environmental issues, the trend is biodegradable lubricant so vegetable oil is a promising candidate. Vegetable oils have been used as substitute for mineral based oil due to their natural biodegradability, non-toxicity and excellent lubricity [1]. But when viewed from a different perspective, vegetable oils still have major limitations such as high and fluctuating prices, thermal and oxidation instability, and low temperature problem [2]. These limitations are sometimes improved with additives. But the mixing of additives is only justified if the additives are biodegradable and non-toxic when considering producing a biodegradable lubricant. Currently additives on the market such as ZDDP, TCP and some other additives contains several active elements such as S, P, N or some other heavy metal elements [3-5]. So in a fundamental study for investigating biodegradable lubricants it is best to not to introduce additive mixing for it is hard to find biodegradable and non-toxic additives on the current local market. Nonetheless, the current local scene for biodegradable lubricants is still under researched and a simple study using vegetable oil such as palm oil should be sufficient and steps to improve it can be taken from this study. Moreover, this study also emphasis on the use of ionic liquid since this type of liquid shown rapid progress in terms of usage and found become suitable as lubricant. Currently, most of the ionic liquid lubricants have been studied which consist of midazolam alkyl cation and hexafluorophosphate or tetrafluoroborate root anions [6-8]. Although such ionic liquids show good anti-wear and lubricating properties, their application has been extremely limited due to the corrosion issue to metal pairs, which was caused by the hydrolysis of the anions to form phosphoric acid or boric acid in the presence of water and release of hydrogen fluoride. As one of the most used additives of lubricating oil [6], phosphate can be used to make an ionic liquid possessing both excellent lubrication/anti-wear characteristics and no corrosion issue to metallic friction pairs if phosphate could be modified by being coordinated with some cations that cannot be easily hydrolyzed. Inspired by this idea, a series of ionic liquids consisting of vegetable oil-based lubricant and alkylimidazolium cation were synthesized, and the tribological properties of these ionic liquids as lubricants were studied as well.

2. Experimental Details

2.1 Test Apparatus

Wear tests were carried out on a wear and friction monitoring machine using a pin on plate configuration as shown in Fig. 1.

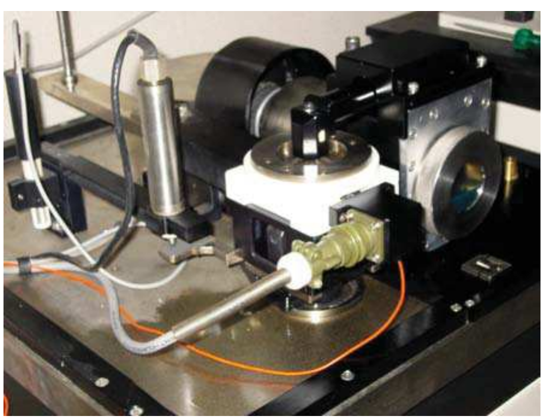

Fig. 1 Wear machine configuration

The pin material used is based from ASTM A600 high speed tool steel (HSS). The plate material used is ASTM A439 Ni-resist austenitic ductile cast iron. On-line measurements were made in the course of each test, including oil bath temperature, instantaneous friction force, coefficient of friction and wear from the sliding pair. Results are measured via a PC linked to the machine and displayed by the software.

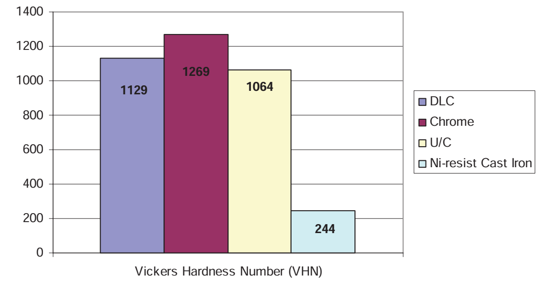

Fig. 2 Vickers Hardness Number for all material samples at 10kgf

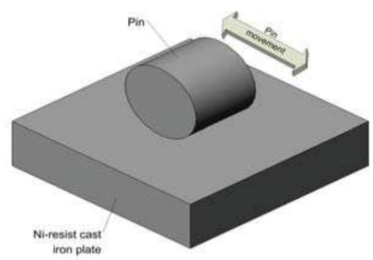

Fig. 3 Schematic diagram of the pin on disk apparatus.

2.2 Test method

The test conditions are as follows; load, 10 – 100N; temperature, 150°C; sliding velocity, 0.13m/s; frequency, 33.3 Hz; stroke length, 2mm; test duration, 30 minutes. This all adds to approximately 240 meters of sliding distance. Before and after each test, specimens are weighted to determined weight and mass loss. Upon completion of each test, specimens were cleaned and prepared for scanning electron microscopy (SEM). Used oil samples of each test were collected for checking ferrous metal debris using PQ/PQ90A dual-coil magnetometer.

2.3 Lubricant

In this investigation a type of ionic liquid namely alkylimidazolium diethyl phosphatesionic has been synthesized by Great Wall Oil Company and Palm Polyol was produced by Advance Oleochemical Technologies Development-MPOB were mixed stoichometrically as lubricant base oil. There are no additional additive was used in this study in order to get fully information on wear behaviour of this base oil and its effect on coated/uncoated material.

The molecular structure of ionic liquid and key properties of base oil sample is showed in Fig.4 and Table.1 respectively.

Fig.4 Molecular structures of Alkylimidazolium Diethyl Phosphates ionic liquids

Table.1 Key properties of oil sample

Properties	Ionic Liquid	50%w Ionic Liquid + 50%w Palm Polyol
Kinematic Viscosity (mm^2/s) 40 °C 100 °C	 137.8 16.6	 188.4 70.25
Viscosity index	129	120
Density(kg/m^3)	1148	1244
Appearance	Light Brown	Yellowish

3. Results and discussions

3.1 Effects of load on wear rate and COF

Wear measurements were carried out using a linearly variable differential transformer (LVDT). Wear rates, calculated from the LVDT measurements, are shown in Fig. 5, as a function of the loads used in the tests.

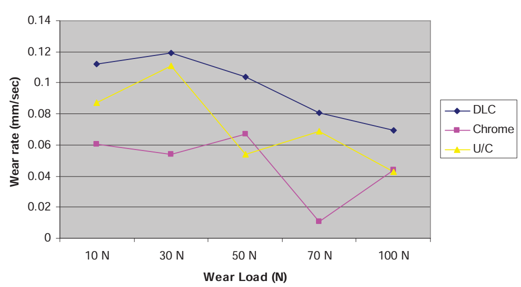

Fig 5. Wear rate (mm/sec) vs. load (N) for all samples

Fig. 5 shows higher wear rates in when using small loads (10N and 30N) compared to higher loads (etc 70, 100N). The only explanation to come up with is that with higher loads there is more pressure on the lubricant which leads to less viscous shear losses in the lubricant film. Viscous shearing will help to build up sufficiently thick film to separate the two surfaces but this will also increase friction coefficient as shown in Fig. 5 as it will require more force to overcome the viscous shearing of the lubricant. Overall DLC shows higher wear rate compared to other samples. Chrome coated HSS shows smallest wear rate which is near to uncoated HSS pin. Wear resistance might also be related to microhardness of coatings. As shown in Fig. 2, chrome coating exhibited higher hardness which also shows lower wear rate in Fig.5 meaning possessing better wear resistance. However, the better wear resistance of uncoated HSS compared to DLC cannot be explained in this way. It may be explained by the DLC coating debris from the pin may have help in increasing the wear rate unintentionally.

Friction coefficient is highest for DLC coated pin maybe because of the coating chipping from the base material of HSS which adds excessive debris in the lubricant. And chrome coating show lowest COF maybe because of the oxides formed on soft coatings (copper, iron, aluminum, nickel, zinc, chromium**).** These oxides may improve the lubricity of soft coatings [9]. In environments containing oxygen such as air, a thin (about 1 to 10nm thick) oxide layer is formed very quickly on most metal surfaces. Oxides layers are sheared more easily than the metal and sometimes they form a very hard layer. Even if the oxide wear layer particles are hard, their abrasive effect is not necessarily important because of their small dimensions compared to the roughness of the surfaces of their embedment into the soft coatings. Sometimes the oxide particles agglomerate to layers strong enough to carry the load.

Also during the tests, experiments at 100N showed a stabilized condition compared to lower loads which had more vibration and shaking. A stabilized condition could also lead to less wear rate and lower coefficient of friction. The only explanation is that 100N is the optimum and sufficient force to be used on this kind of experiment running on this machine.

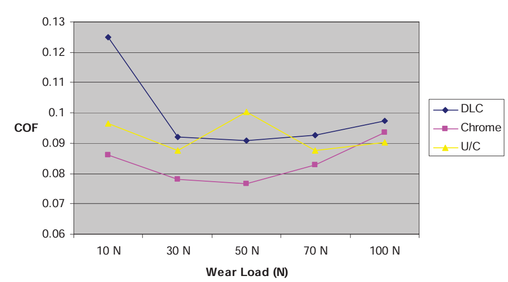

Fig.6 Coefficient of friction (COF) vs. load (N) for all samples

3.2 Worn surface characteristics

The appearance of the surface damage on the pins and plates is shown in Fig.7. Surface examinations of the worn specimens were done by SEM. These are taken after running test with 100N load, 2000 rpm, 100 ºC and 30 minutes of running time. Fig. 7(a) shows mild abrasion on the surface of chrome coated pins while the plates in Fig 7(d) shows very little scars on the surface. The surface of the DLC pin shown in Fig. 7(b) clearly indicates some moderate wear on the surface and could come to the conclusion where there is some of the DLC coating has been chipped off. But the surface of the cast iron plate shows no signs of heavy scarring. Fig. 7(c) shows heavy wear abrasion on the uncoated HSS pin when sliding on Ni-resist cast iron plates. By visual inspection, chrome coating provides the least wear when sliding on Ni-resist cast iron plates.

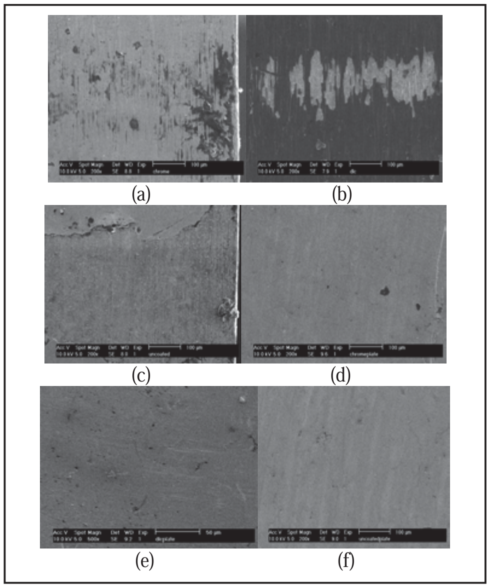

Fig. 7 Surface examinations of the worn specimens

Another explanation of why chrome coating shows less wear than DLC coating is the kind of lubricant used. Palm-polyol is a bit acidic as it is vegetable based oil compared to other mineral oils. The chemical reaction of palm-polyol may interact well with the chrome coating compared to DLC coating when the surfaces slide which provides less corrosive wear. Corrosive wear occurs in situations where the environment surrounding a sliding surface interacts chemically with it.

3.3 Total weight loss

As expected with higher load there will be higher total weight loss for all samples. On the contrary for 100N, it seems the total weight loss of pin and plate has considerably decreased. This can be explained by the less vibration due to more stabilized condition when using load at 100N similar as the trend in wear rate before this. Total weight loss of specimens is shown in Fig. 8.

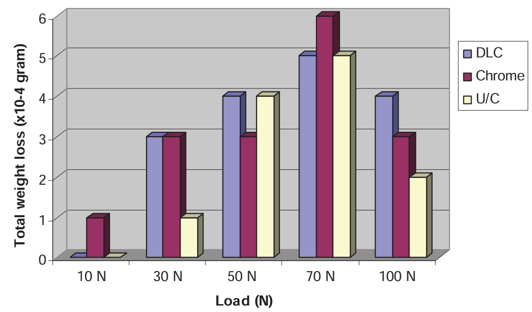

Fig.8 Total weight loss for all specimens (pins and plates)

3.4 Used lubricant oil analysis

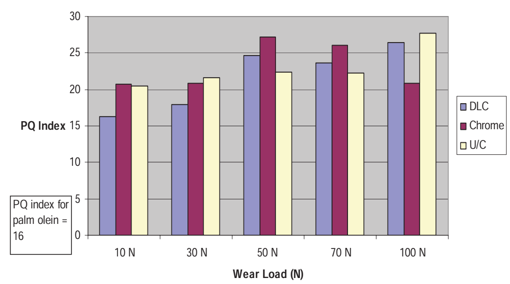

Fig. 9 PQ index result for all used oil samples.

Samples of used oil were taken from each test and checked for ferrous metal debris using the PQ/PQ90A dual-coil magnetometer. Results are shown in Fig. 9. The higher the PQ index number implies that are a higher quantity of metal debris in the oil sample. Apparently, at higher loads, more debris is found in the used oil samples compared to lower loads. At 50N, chrome coat shows higher PQ index number compared to others. This is also the same for 70N.But chrome coating HSS shows lowest PQ index number when running at the highest load (100N) compared to the other samples. DLC oil samples show low PQ index number at low loads but slowly rises when the load is increased. More wear implies more debris in the oil. But uncoated shows highest PQ index number when run at 100N. This result shows uncoated HSS still isn't enough to withstand wear and friction at very high loads.

4. Conclusions

Some conclusions have been made to gain better understanding of the tribological behavior of sliding DLC and chrome coatings of high speed steel on Ni-resist cast iron while lubricated with palm-polyol. The following conclusions drawn are:

1. Chrome coating exhibit excellent wear resistance compared to DLC coating and uncoated HSS when using palm-polyol blended ionic liquid as the lubricant.
2. Wear rate of chrome coating was better than DLC coating HSS and uncoated HSS and this was the same for coefficient of friction of the test specimens.
3. Usually, wear rate is influenced by the microhardness of specimen except when in cases where excessive wear debris is taken into consideration of increasing the wear rate.
4. SEM of worn surfaces revealed few scratches on the Ni-resist cast iron plates compared to mild abrasive wear on the pins.
5. With higher load, the higher the PQ index number is. As higher load causes higher wear which leads to more wear debris in the used oil.
6. Palm-polyol blended ionic liquid shows good potential of lubricating purposes for the specimen used in this test as mild wear is reported from the experiments. Importantly palm-polyol is renewable and biodegradable compared to other lubricants.
7. Palm-polyol as well as ionic liquid is a promising candidate for biodegradable lubricants though its shows small complications on DLC coatings in certain conditions.

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