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ANALYSIS OF THE SURFACE LAYER FORMATION OF SINGLE CYLINDER ENGINE COMBUSTION CHAMBER WITH PHOSPHOROUS-FREE AND CONVENTIONAL ENGINE LUBRICANTS

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Abstract: *Phosphorus-free engine lubricants are gaining importance for preventing catalyst poisoning which is the major deactivation mechanism that causes three-way catalyst malfunction. The main purpose of this paper is to evaluate the mechanism of surface layer formation in combustion chamber of spark ignition engines with phosphorous-free and phosphorous containing mineral engine lubricants. An experimental endurance test was conducted for 100 hours at equal load conditions for each lubricant. Endurance tests were run with a laboratory engine test bench. Subsequently, engines dismantled and cylinder liners were cut accurately to obtain specimens for microscopic examination. Optical microscopy, scanning electron microscopy and energy dispersive X-ray spectroscopy methods were used for evaluation.*

Elemental measurements on the surface which were obtained by X-ray spectroscopy were examined statistically. Results of the experiments showed that phosphorous containing lubricant deposited more carbon and oxygen although less manganese and silica than the phosphorous containing rival. After the X-ray spectroscopy of the combustion chamber surface at top dead centre, iron element composition of the phosphorus-free lubricant was notably higher than phosphorus containing oil.

Keywords: *Phosphorous-free Oil, Combustion chamber, X-ray spectroscopy, Additive layer formation, Cylinder liner*

1. INTRODUCTION

Mechanical losses are responsible for the approximately 10-15% fuel energy loss. Half of the mechanical losses are generated by the friction between piston rings and cylinder liner. Therefore, the performance of the piston ring and cylinder liner tribological pair is the indicator of the performance and the lifespan of an internal combustion engine [1]. Particularly, wear around top dead centre is the main limiter of effective engine life. Piston rings are intended to maintain the dynamic sealing between crankcase and the combustion chamber which minimize the power losses caused by the blow-by mass transfer through the crankcase during expansion stroke [2]. Success of this sealing mainly depends on the wear rate of ring and liner pack which are primarily the function of the formed tribofilm on ring and liner surfaces. Engine lubricants are formulated to generate and sustain the protection against wear while lubrication, cooling and cleaning of the surfaces are also expected from lubricant. Modern engine lubricant can satisfy these demands with chemical compounds like anti-wear additives, anti-oxidant additives, dispersants, detergents etc. [3]. Additives also enhance the chemical composition of base lubricant [4].

Zinc dialkyldithiophosphate (ZDDP) lubricant additives are the most effective anti-wear and anti-oxidant additives in the cost and performance perspectives [5]. Therefore, it has been in use for decades. Although, ZDDP mainly contains phosphorus which is a well-known poison for three-way catalysts [6]. Environmental concerns become more dominant among authorities and individuals which result stricter emission regulations [7]. Automotive manufacturers are pressurised to produce cleaner vehicles in all terms from well to wheel. Harmful exhaust emissions are reduced through after-treatment systems like diesel oxidation catalysts, three-way catalyst and diesel particulate filters. Poisoning phenomenon related with lubricant has to be prevented, and hence, new and emerging technologies have become important. The solution is complex, namely reducing the amount of phosphorus, sulphur, zinc and magnesium without deteriorating the performance of the oil [8].

This study intended to investigate the interaction between phosphorus containing (PC) and Non-phosphorus and non-ash containing lubricant (NPNA) on the combustion chamber surface of internal combustion engines. An endurance test was conducted with two of the identical spark ignition engines. Both engines aged during 100 hours under certain load conditions which were determined according to standards. Liner surfaces are examined with electron, optical microscopy and energy dispersive X-ray spectroscopy techniques.

2. EXPERIMENTAL DETAILS

Experimental study consists of two equal endurance tests with two identical engines, specifications of which are listed in Table 1. Endurance tests were performed after a run-in period and a consecutive oil drain.

Table 1. Specifications of test engines.

Designation	Value/type
Manufacturer/Model	Honda/GX 200
Type	4-stroke air-cooled, SI
Aspiration	Naturally aspirated
Lubrication method	Splash
Number of cylinders	1
Bore x Stroke (mm)	68 x 54
Cylinder volume (cm^3)	196
Compression ratio	8.5:1
Crankcase oil capacity (l)	0.6
Speed max (rpm)	3600
Rated torque (Nm)	12.4@2500 rpm
Rated power (kW)	4.1@3600 rpm

ISO 8178 standard was selected as a reference to determine load conditions and a direct current generator was used to generate the brake load [9]. An overall scheme of the test bench is shown in Figure 1. A specially formulated NPNA lubricant and a conventional PC lubricant were used for the tests, specifications of which are listed in Table 2 under the courtesy of IDEMITSU KOSAN CO. LTD. Japanese petrochemical company.

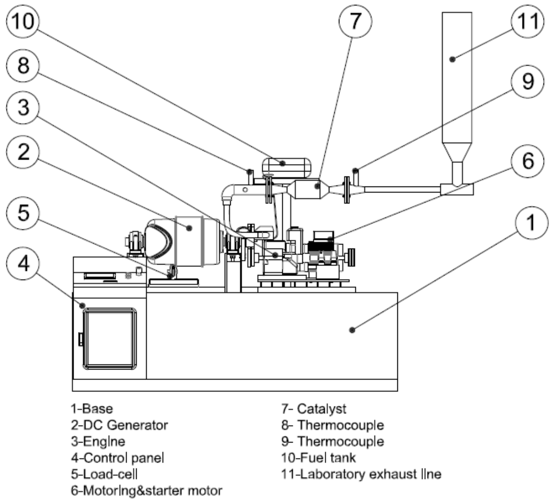


Figure 1. Schematic, CAD and real view of the test bench.

Table 2. Specifications of test oils.

Specification	PC	NPNA
SAE grade	10W30	10W30
TBN (mgKOH/g)	5.73	3.13
Viscosity 100 °C (cSt)	10.4	10.3
Viscosity index	139	142
Flash point (Celcius)	224	240
Specific gravity@15 °C	0.874	0.862
Ca content (wt %)	0.2	0
Zn content (wt %)	0.09	0
S content (wt %)	0.19	0.18
P content (wt %)	0.08	0

Operating conditions are summarized in Table 3 for both types of engine oils. PC and NPNA lubricant were aged during 100 hours under certain loading conditions, at the end of the test, cylinder liner and piston rings were machined to obtain specimens for microscopic analysis.

Table 3. Details of load conditions.

Specification	PC	NPNA
Engine speed (rpm)	2500	2500
Engine load (%)	75	75
Endurance test duration (h)	100	100
Ambient temperature (Celcius)	22±3	22±3

Typical composition of cylinder liner was required to obtain better assessment of the surface which had been provided by the engine manufacturer and these are listed in Table 4. Specimens had been ultrasonically cleaned with n-hexane.

Table 4. Typical composition of cylinder liner.

Element	Composition % mass
Fe	93.97
P	0.3
V	0.15
C	3.00
Si	2.00
Mn	0.60

3. RESULTS AND DISCUSSION

Top dead centre is the most complex surface for the tribologists where the conditions are extreme. Combustion induced pressure gradient acts upon top ring and hence contact between liner and ring surface reaches top levels and conditions become severe. Furthermore, combustion gases and soot controversially affect the lubrication in TDC area, acidic compounds, unburned hydrocarbons and soot accumulation on liner surface occurs with constant replenishment cycle. In addition to the factors explained above, high gas temperature reduces oil viscosity which also has detrimental effect on liner-ring lubrication. Base number retention capability and high temperature and high shear rate viscosity (HTHS) of engine lubricant become excessively important on TDC lubrication as well as the performance of anti-wear additive. Total base number indicates the ability of engine oil to neutralize acidic compounds which primarily originate from combustion chamber and transfer through the liner to the crankcase. The more the base number retention, the lower the oxidative wear on liner surface especially around TDC.

Downsized engines with turbochargers are on-going trend to fulfil the requirements of CO_2 emission reduction and fuel economy [10]. Low load fuel economy and torque flexibility make these types of engines favourable although increased boost levels result significantly higher contact pressures. Therefore, HTHS viscosity gains attention with rising in-cylinder pressure which is the wellness of lubricant performance under severe operation conditions.

Layer formation of anti-wear additive on TDC surface is the main factor for decreasing the liner wear. Anti-wear additive acts like buffer between ring and liner asperities and prevents adhesion. Accumulated additives on surfaces can effectively be detected through electron microscopy technique. Besides, it is possible to detect elemental distribution with X-ray spectroscopy method.

Equal tear-down processes were applied to test engines, which include dismantling of cylinder liners and piston rings. Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) were applied on TDC region of cylinder liner as shown in Figure 2 and Figure 3.

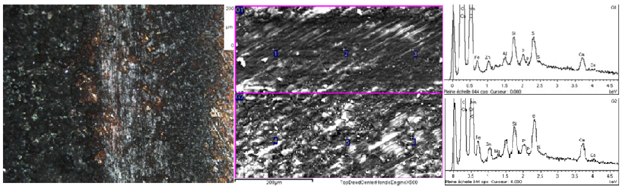


Figure 2. Optical, SEM and EDS results of PC lubricant.

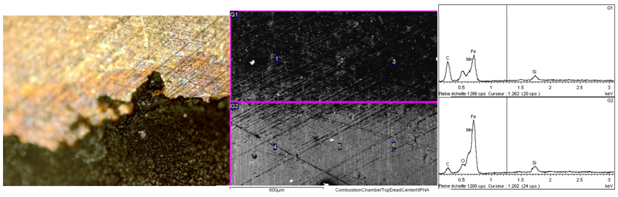


Figure 3. Optical, SEM and EDS results of NPNA lubricant.

Labels on figures indicate the location of the inspection: G1 designation borders the combustion chamber surface where the sweep motion of top ring has ended G2 designation indicates liner surface covered by piston crown. Representation of inspected surfaces are depicted in Figure 4, analyse points were determined by considering the surface layers of additive accumulation.

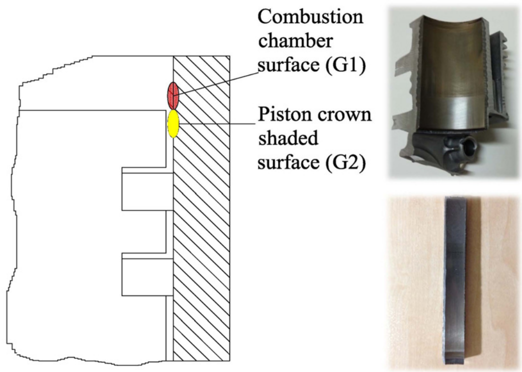


Figure 4. Schematic representation inspected surfaces.

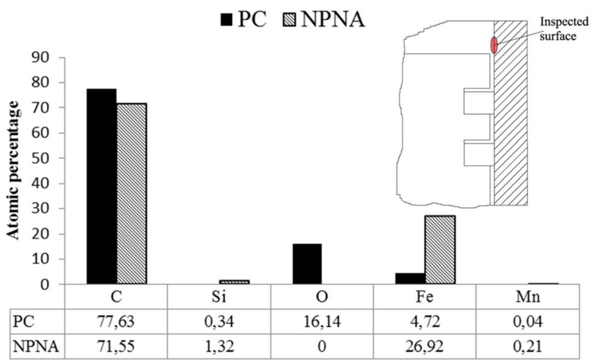
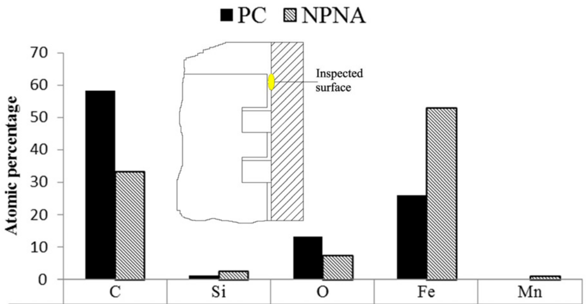


Figure 5. EDS result of combustion chamber surface.

EDS measurements were applied for both of the surfaces lubricated with test oils. Figure 5 shows the elemental composition of layer on the surface of combustion chamber. Higher amount of carbonaceous deposit was detected with the PC lubricant on combustion chamber surface. Similar trend observed for G2 surface as shown in Figure 6 while atomic concentration is different.



	C	Si	O	Fe	Mn
PC	58,36	1,31	13,32	25,92	0,2
NPNA	33,1	2,62	7,45	52,75	0,84

Figure 6. EDS result of TDC surface.

Carbon and oxygen levels indicate the oil film on both of the surfaces while the G1 surface environment is quite different than G2. Higher carbon concentration of PC surface of combustion chamber can be attributable to accumulation of swept portion of surface oil film.

4. CONCLUSSION

Newly developed catalyst friendly phosphorus-free engine oil and a conventional ZDDP containing engine oil were tested by applying 100 h long endurance study. Two of identical engines were aged under equal loading conditions then dismantled and analysed. The main subject of the investigation is the additive layer formation of lubricant on combustion chamber surface. Considering the measurements and observations made with optical microscope, SEM and EDS, findings can be summarized as;

A- Higher level of deposit formation was detected with PC lubricant on both combustion chamber and piston shaded surfaces.

B- PC conventional lubricant mainly differs from NPNA with oxygen content on combustion chamber surface; this discrepancy originates from the type of deposited compounds.

C- Lower deposits with NPNA on combustion surface indicate the effect of lubricant on carbonaceous deposit formation.

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