Design of Piston Ring Surface Treatment for Reducing Lubricating Oil Consumption

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Abstract
The reduction of lubricating oil consumption in the internal combustion engines is important for clearing the emission standard and environmental problem, especially the hydrocarbon and particulate matter. Recently, it is reported that lubricating oil which exist near the piston ring or piston crown effects strongly for occurrence of pre-ignition in highly supercharged spark ignition engines. This paper describes results of a study on the mechanism of lubricating oil consumption from the top ring with piston motion. The experimental and calculated data show that it is effective the surface treatment of piston ring to reduce lubricating oil consumption. The wetting angle on the piston ring and the viscosity of the lubricant oil are key parameters for lubricating oil consumption from the top ring.
Keywords: design, piston ring, surface treatment, lubricating oil

1 Introduction
Recently, downsize of displacement volume is one of the important concept to reduce emissions as well as fuel consumption in the spark ignition engines. The downsize may shift the operating point toward higher thermal efficiency. It is pointed out that the droplets of lubricating oil near the ring crevice or piston crown contribute to oil consumption and abnormal combustion especially pre-ignition in the SI engines. This paper focuses on the mechanism of scattering oil droplets on the piston ring during engine operation (in **Fig.1**) .

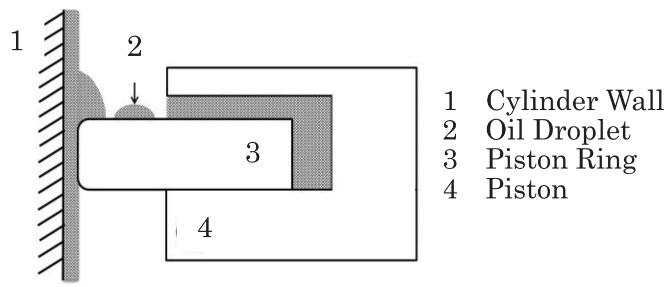

Fig.1 Mechanism of oil consumption

2 Calculation model
2.1 Calculation model
The calculation model expresses the process which the droplets of lubricating oil on the piston ring are scattered by the reciprocating motion of the engine, namely the proposed model evaluates effects of oil properties as viscosity and surface tension, inertia with piston motion on the scattering the lubricating oil droplets on the top ring surface. **Figure 2** shows outline of the proposed model.

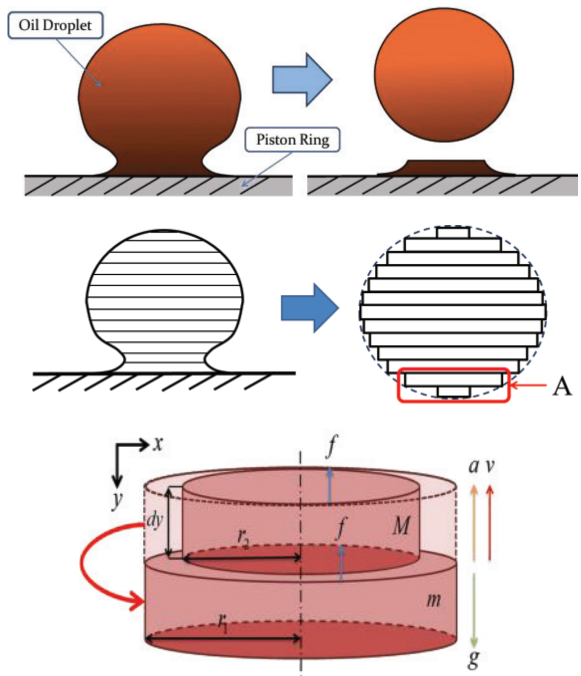

Fig.2 Calculation model

A droplet of lubricating oil on the top ring is considered to be piled up thin disks as shown in **Fig.2**. In the portion A in **Fig.2** which exist two thin discs in the control volume, it is calculated the balance of inertia, surface tension, viscosity and gravity, and mass conservation between upper and lower thin discs. If the volume of lowest thin disc equal zero, the model is treated that the droplet of lubricating oil scatter to the in-cylinder from the surface of top ring. The governed equations of the proposed model as follows.

$$(M-m)(-a+g)-2\pi f_T(r_2-r_1)-\mu\frac{\partial u}{\partial x}A=0 \qquad (1)$$

$$\rho\frac{dv}{dt}=\rho\frac{dA}{dt}dy=2\pi\rho\left(\frac{dr_2}{dt}-\frac{dr_1}{dt}\right)dy=0 \qquad (2)$$

The equation (1) expresses balance of force, where M and m are mass of upper and lower thin discs, a is acceleration of piston, μ is viscosity of lubricating oil, u is relative speed between upper and lower thin discs. The equation (2)expresses the conservation of mass, where v is volume of thin discs, r is radius of thin discs.

2.2 Results of calculation

Figure3shows calculated results of lubricating oil diameter which is the closest position of the piston ring surface, consequently if the diameter is zero in **Fig.3**, the droplet apart from piston ring surface to the cylinder. The input data of the calculation in **Fig.3**are property of 10w-30 oil, wetting angle without surface treatment of piston ring and engine speed at2000rpm. The results show that the small droplets (size is between piston and cylinder wall) of the oil has the potential for scattering to the cylinder. The timing of crank angle which the diameter equal zero means the relative frequency of scattering of oil droplets, namely, the oil droplet of 250μm is easy to scatter 1.8 times for its 500μm.

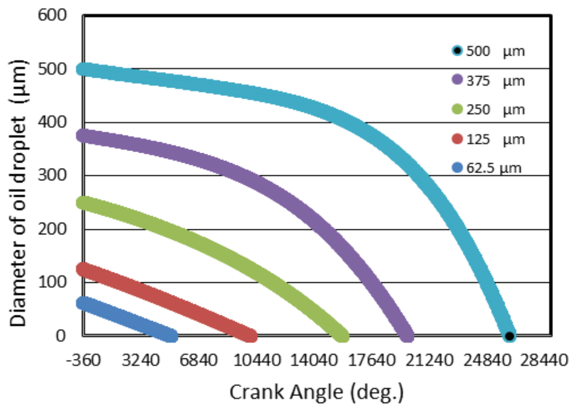

Fig.3 Droplets size on piston ring for crank angle

Figure4 shows effect of engine speed on oil consumption. The engine speed was faster, the frequency of scattering was higher both 0w-20 and 10w-30 oils. However, the 0w-20 oil accelerated scattering oil. This is supposed the different of viscosity. It is mentioned generally that the viscosity effects on oil consumption strongly. These calculated data express the behavior of the oil consumption in a fore stroke reciprocating engine.

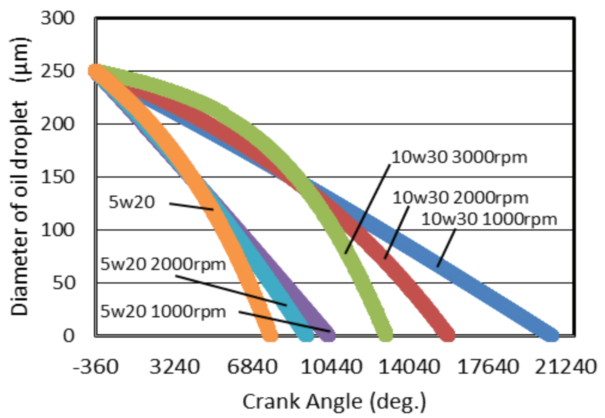

Fig.4 Effect of engine speed on oil consumption

The data of wetting angles are measured experimentally (Ref. Experimental approach). The wetting angle of measured data are as follows, a 10w-30 commercial lubricating oil without silicone coated is 5.65degree, with silicone coated is 21.27 degree, a 0w-20 commercial lubricating oil without silicon coated is 9.55 degree and with silicon coated is 18.27 degree.

Figure5 shows effect of wetting angel of the piston ring surface on oil consumption. In the 10w-30 oil, the wetting angle increases 3.8times, the calculated data expresses that the oil consumption increase 1.3times. In the 0w-20 oil, the wetting angle increases 1.9times, the calculated data expresses that the oil consumption increase 1.1times.

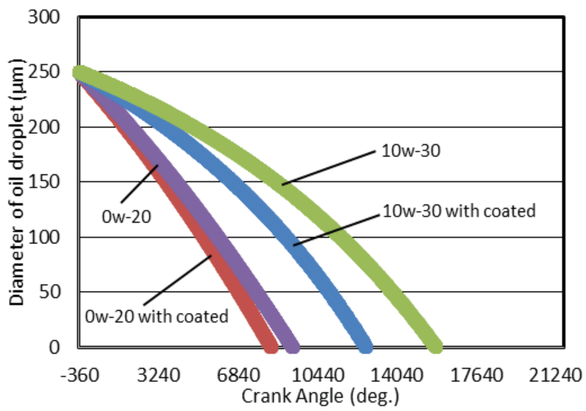

Fig.5 Effect of wetting angle on oil consumption

In order to prevent the effectiveness of oil additive in a commercial oil, it is selected the turbine oil #68 which is no included additive in this research.

Figure6 shows effect of surface tension on oil consumption. In the turbine oil #68, the surface tension is 36.6 Nm which is 1.5times of the 10w-30 oil. However, the calculated data show the oil consumption increase 1.37times. This is because that the effect of wetting angle is strong compared with surface tension. In the turbine ST +12% oil, the surface tension increase 1.12times, the calculated data show that the oil consumption decrease 0.88times. In the turbine ST+21% oil, the surface tension increase 1.21times,the calculated data show that the oil consumption decrease 0.83times.The increase of the surface tension shows the

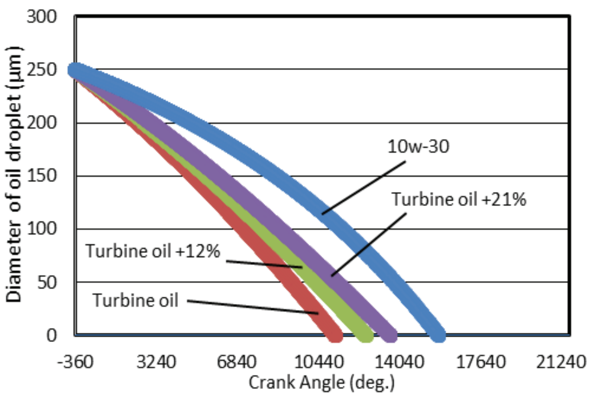

Fig.6 Effect of surface tension on oil consumption

correlation at the oil consumption in this model. However, the effect of wetting angle and surface tension are mild compared with the viscosity effect in this model.

Figure 7 shows summary of calculated results. The vertical line of the graph means non dimensional oil consumption which based on relative value at using10w-30 without surface treatment. The wetting angle on the piston ring and viscosity of the oil were strongly effected on scattering oil, namely lubricating oil consumption.

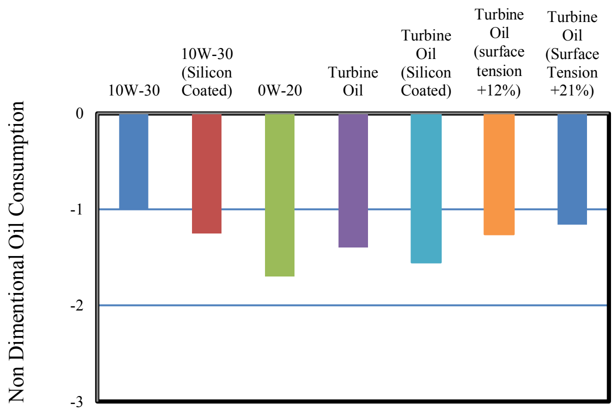

Fig.7 Summary of calculated results

3 Experimental approach

The measurement of characteristic between piston ring surface and lubricating oil were carried out. The results of measurement were evaluated by the engine test.

3.1 Surface tension and wetting angle of tests oils

In order to assess effect of surface tension of lubricating oil, the test oil added surfactant and adjusted to increase the surface tension in +12% and +21%. The increase of surface tension may be against the scattering lubricating oil from piston ring. The measurement of surface tension carried out the capillary tube method which is shown in **Fig.8**. **Table 1** shows measurement results of surface tension of test oils.

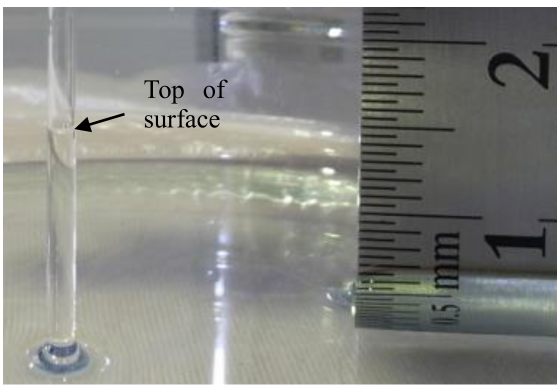

Fig. 8 Measurement of surface tension of test oils

Table 1 Surface tension of test oils

Lubricating Oil	Surface tension [Nm]
10w-30	24.1
0w-20	27.6
Turbine oil#68	36.3
Turbine ST+12%	40.6
Turbine ST+21%	43.9

In order to assess effect of wetting angle of the lubricating oil on the piston ring, only upper surface of the top ring was coated with silicon film. The treatment may increase the wetting angle on the engine tests. **Figure 9** shows a photograph of the test oil on the coated piston ring. The right part in **Fig.9** was a test oil with coated surface. **Table 2** shows measurement results of the wetting angle.

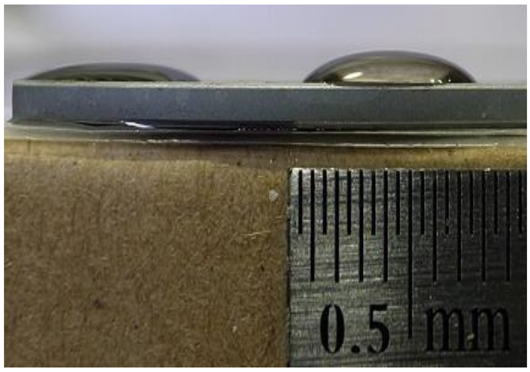

Fig.9 Measurement of wetting angle on piston ring

Table 2 Wetting angle of test oils on the piston ring

Lubricating Oil	Surface treatment	Wetting Angle [deg]
10w-30	without	5.65
	with	21.27
0w-20	without	9.55
	with	18.27
Turbine oil #68	without	22.5
	with	29.0

3.2 Engine tests

The test engine used for the experimental investigations was air- cooled small SI engine as shown in **Table 3**.

The oil consumption is measured by mass of oil in the engine. The oil is drained from the engine and measured by electric balance. Before experiments, the lubricating oil is took into and drain from the engine to confirm the precision of the data.

Table 3 Engine spec. and test conditions

Type	Air cooled 4stroke SI (Single cylinder)
Bore×Stroke	84.0 ×61.0
Engine speed	2000rpm
Load	1/2
Fuel	Regular Gasoline (RON 90)
Test Duration	1.0 hour

The test procedure of lubricating oil consumption is as follows,

(a) The engine is cleaned up by the fresh oil operation.

(b) The lubricating oil which used to clean up is drained out.

(c) The test oil is taken into the engine, and it is warmed up sufficiently.

(d) The engine is operated at 1/2 load,2000rpm for 1.0 hour.

(e) The lubricating oil is drained out from the bottom of the engine. It takes time for 10minuits.

(f) The lubricating oil which is drained and measured by electric balance.

It is carried out five times for an experimental condition.

Figure 10 shows the results of lubricating consumption of the engine tests. The results show that the oil consumption with silicon coated piston ring increases sharply compared with basic condition (10w-30 without silicon coated). This is mean that the wetting angle on the top ring effects strongly on oil consumption in the practical use. In the condition with turbine oil, the data show similar behavior on the case of wetting angle. However, the behavior of oil consumption is instable to the surface tension. On the other hand, the effect of surface tension of the lubricating oil is mild for lubricating oil consumption. The viscosity of the lubricating oil were lower 10w-30 to 0w-20,the oil consumption increases sharply up to twice.

There are a lot of reports about the effective of viscosity for oil consumption. They say that lower viscosity of the oil occur worse oil consumption. In this research, the viscosity of the test oils are 72.4 mPa·s (0w-20), 169.2 mPa·s (10w-30) and 111.8mPa·s(turbine oil) at 313K. The experimental data suggest that the impact of properties of oil and piston ring surface for lubricating oil consumption. Namely, the control of wetting angle on the top ling has potential for reduce the lubricating oil consumption as well as viscosity and the adjustment of surface tension of the oil has it too, but mild than previous properties.

This experiment suggests that it is effective for reducing lubricating oil consumption to make some treatment with the top ring surface which decrease wetting angle.

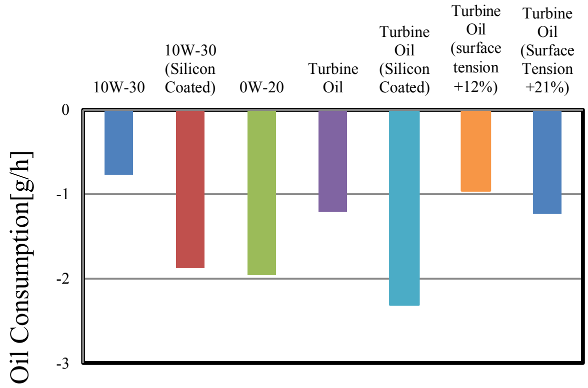

Fig.10 Results of oil consumption by engine tests

In this research, cause of lubricating oil consumption in a fore stroke reciprocating engine ware analyzed. It is proposed the mechanism of lubricating oil consumption which includes the cause of pre-ignition in a super charged spark ignition engine by oil droplets on the piston ring surface. There is surplus lubricating oil to keep the oil film in the tough operating condition for protection the engine parts and smooth piston motion near the top dead canter. This research suggests that the surplus lubricating oil on the top ring is one of the cause of oil consumption.

This research focuses on the relation of piston ring surface and lubricating oil properties, such as wetting angle, surface tension and viscosity. The approaches are both numerical calculation and experiment.

The calculated data show the small size oil droplets on the piston ring such as width between piston and cylinder wall can scatter at low engine speed. This model is able to explain the mechanism of the scattering of lubricating oil on the piston ring. The tendency of calculated data for each properties coincide with the experimental data.

The wetting angle of piston ring surface increase 3.8 times, the lubricating oil consumption increase strongly both calculation and experiment. This is mean that the suppression of wetting angle on the piston ring surface is important to reduce the lubricating oil consumption in the reciprocating engines. On the point of Pre-ignition, it should be considered the influence of oil dilution by liquid fuel.

The increase of surface tension of lubricating oil is effective to reduce the consumption, however, it is mild compared with the effect of wetting angle on the piston ring.

6 Conclusions

In this research, causes of lubricating oil consumption on the piston ring were analyzed by numerical calculation and experimental approach.

(1) The calculation model to evaluate the lubricating oil consumption on the top ring has been developed. The model is able to explain the mechanism of scattering oil droplets on the piston ring.

(2) The suppress of wetting angle on the top ring is effective strongly to reduce the lubricating oil

consumption.This study suggested that it is effective for reducing lubricating oil consumption to make some treatment on the top ring surface which decrease wetting angle.

(3) The surface tension of the lubricating oil is effectiveparameter to reduce the lubricating oil consumption, however it is mild compared with wetting angle and viscosity.

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