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Combustion Improvement for Internal Combustion Engine Using a Functional Glass Catalyst into Cooling Water

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As a functional glass of melted grainy was sunk respectively into the cooling water of an engine, the healstone and the magnetite based on the silica were confirmed to the reduction of the fuel consumption, the knocking control of SI engine, and the exhaust emissions of SI and CI engines. As for these characteristics, the combustion improvement became possible by the reduction of the cooling water loss due to the reduction in the surface tension of cooling water with the functional glass and kinematic viscosity and the charging efficiency rise.

Key words: Internal Combustion Engine, Cooling, Fuel Economy/Glass, Coolant, Heat Transfer ④

1. Introduction

Improvements in the fuel economy of internal combustion engines have become indispensable with abnormal rise in crude oil prices, and all possible improvement measures are being taken. As examples of such measures, not only the improvements in the method of combustion but also reduction in various losses such as exhaust, cooling, friction, radiation, gas exchange, etc. is implemented. Among these losses, the loss due to cooling water in water cooling engines is the greatest, being roughly equal to the loss due to exhaust. In general, optimum cooling is required according to the change in thermal load of the engine, but in the event of insufficient cooling, a decrease in the thermal fatigue strength of metallic materials, a rapid increase in thermal stress, an increase in thermal expansion, occurrence of boundary lubrication due to the oil properties of lubricating oil, and a decrease in output associated with a decline in filling efficiency will result. Also, in spark ignition engines, abnormal combustion such as knocking will occur. Hence, under the present circumstances, slightly over-cooling is required in order to avoid the above phenomena in engines for practical use.

Although reduction in cooling loss is employed as a means of improving fuel economy of engines, there are not so many researches on coolants as a method of such improvement [(1)-(3)]. In this research, when particulate functional glass as obtained by dissolving each of the maifan stone and magnetite on the basis of silica [(4),(5)] has been immersed in the coolant of an engine, control of the knocking of an SI engine and reduction in the fuel economy and exhaust emissions have been recognized, and so its basic characteristics are reported below.

2. Characteristics of functional glass

2.1 Composition of functional glass

Functional glass (Bio Glass) is made, as shown in Table 1, by using silica (SiO_2) as a base and using maifan stone (quartz and feldspar porphyry) and magnetite (Fe_2O_4) as major materials, by dissolving each of these at a high temperature of about 1300 - 1400℃. As for this particulate functional glass, the one of 8 mm in diameter whose material is maifan stone is "green" (hereafter called "green") and the one whose material is magnetite is "black" (hereafter called

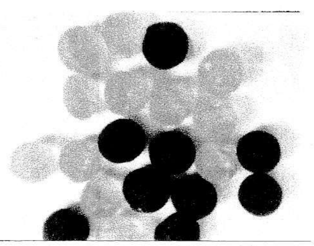

Fig. 1 Appearance of "Bio Glass"

Table 1 Chemical Composition of "Bio Glass" (wt.%)

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO
Quartz	64.59	0.35	16.75	3.30	2.42
Orthopyre	64.01	0.36	16.90	3.49	2.61
Magnetite	37.99	0.18	1.34	14.78	30.66
	CaO	Na_2O	K_2O	Ig.loss	Total
Quartz	2.48	6.88	0.88	2.08	99.74
Orthopyre	2.48	6.73	0.79	2.49	99.85
Magnetite	3.28	1.10	0.13	8.93	98.38

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"black") as shown in Fig. 1, and at the time of use equal amounts of these two are put into a stainless steel tube and immersed in cooling water. The chemical composition of functional glass samples is shown in Table 1. It has been confirmed that the "green" maifan stone has strong far-infrared radiation characteristics, deodorizing action, antibacterial action, ultra-hydrophilic properties, and reduction activity functions, and is used for water treatment and a deodorizer. Black magnetite has an iron oxide as its major constituent, having magnetism and electrical conductivity, and is used as a steel making material.

2.2 Far-infrared emissivity and hydrophilic properties of functional glass

A comparison of far-infrared emissivity and hydrophilic properties between functional glass samples and ordinary glass (soda lime glass) is shown in Table 2. Also, a comparison of the contact angles of droplets of water on a substance composed of glass that shows hydrophilic properties in a similar manner is shown in Fig. 2. The far-infrared emissivity of functional glass is 87 - 89% which is higher than that of ordinary glass by 9 - 27%, with the radiating energy at this time being 3.50 - 3.58 x 10^2 W/m^2. In addition, the contact angles of droplets of water on a glass surface for the two types of glass were measured by using a contact angle measuring instrument (CA-X150 manufactured by Kyowa Interface Science). As a result of this, the contact angles using functional glass were 4 - 5° in the case of "green" and 6° in the case of "black" as shown in Fig. 2, which showed that both types of functional glass have ultra-hydrophilic properties as compared with 62° with ordinary glass.

Table 2 Comparison of Far-infrared Emissivity Rate and Water Contact Angle on "Bio Glass" and Conventional Glass

	Bio Glass		Conventional Glass
	Healstone	Magnetite	
Melting Temperature ℃	1300~1400		1300~1400
Far-infrared Emissivity Rate %	87~89		60~80
Water Contact Angle °	4~5	6	62

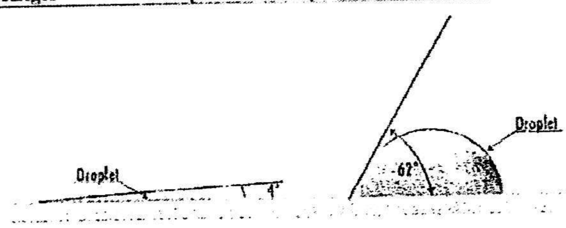

Fig. 2 Effect of "Bio Glass" on Water Contact Angle

2.3 pH value of functional glass

pH (power of hydrogen) shows the degree of acidity or alkalinity of a substance by means of the exponent of hydrogen ions (H-) in the substance. With regard to acidity, pH = 0 for hydrochloric acid, with regard to alkalinity pH = 14 for sodium hydroxide, and with regard to neutrality pH = 7 for pure water.

Fig. 3 shows variation in the pH value with temperature changes between 30 and 85°C that were measured using functional glass in pure water (distilled water) and a solution of coolant (Diaqueen coolant; 30% in concentration). Fig. 3 represents a tendency that the pH values of pure water, coolant solution, functional glass/pure water and functional glass/coolant solution rise slightly with a temperature rise in each of the liquids. This tendency of increase in pH resulting of immersion of functional glass was great when using pure water, with a rise of about 7%, whereas there was hardly any change in the case of coolant solution. Hence, it has been found that the rise in pH caused by functional glass is noticeable in the case of pure water-based samples. It is conjectured that the ion exchange characteristics of functional glass exert a greater influence when pure water is used.

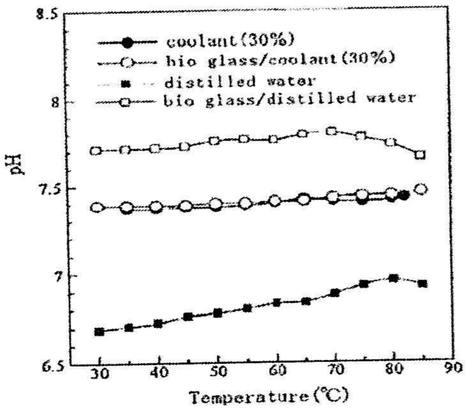

Fig. 3 Variation of pH of "Bio Glass" in Distilled Water and Coolant with Temperature Change

2.4 Viscosity and oxidation-reduction potential of water in which functional glass is immersed

Table 3 shows variation in viscosity μ when 100 cc each of pure water and tap water in which 4 "green" samples and 4 "black" samples of functional glass were immersed and the water was circulated for 14 days with a pedestal pump as compared with the viscosity of pure water.

As a result of this, the viscosity μ at room temperature right after measurement was 0.8050 mPa-s both in the case of pure water in which functional glass was immersed and in

Table 3 Effect of "Bio Glass" into Distilled Water and Tap Water on Viscosity μ (mPa・s)

	Elaped Time		
	0 min	7 Days	14 Days
Distilled Water	0.8050	0.8050	0.8023
Bio Glass/ Distilled Water	0.8050	0.8018	0.8009
Tap Water	0.8107	0.8069	0.8076
Bio Glass/ Tap Water	0.8102	0.8047	0.8020

Table 4 Effect of "Bio Glass" into Tap Water on Redax Potential: *ORP* (-mV)

	Elaped Time (min)							
	0	10	20	30	40	50	60	70
Tap Water	345	—	—	—	—	—	—	—
Bio Glass/ Tap Water	558	667	682	688	691	691	692	690

the case of pure water, and 14 days later the values were 0.8023 and 0.8009 mPa-s, respectively, with a decrease in viscosity in both cases, at rates of 0.40% and 0.17%, respectively. With regard to the viscosity μ of the tap water-based solution, the viscosity of water in which functional glass was immersed decreased by 0.06% right after measurement as compared with that of tap water, and after 14 days there was a decrease of 0.69% in a similar comparison, and there were decreases in viscosity relatively in proportion to elapse of time with both pure water-based and tap water-based solutions. The amount of such reduction was greater with pure water than with tap water, and the decrease in viscosity was slightly smaller with water in which functional glass was immersed than water that formed the base in proportion to elapse of time. Therefore, it has been found that water in which functional glass is immersed has characteristics that decrease viscosity.

Next, Table 4 shows the result of measurement of the oxidation-reduction potential (*ORP*) of functional glass at room temperature using tap water-based solutions. The *ORP* of tap water was -345 mV, whereas the *ORP* of water in which functional glass was immersed was -558 mV right after immersion, thus showing a value of 1.7 times of the value of tap water, and it increased in proportion to elapse of time, but after 40 - 70 minutes it became saturated after increasing to -690 to -692 mV which is a value about twice that of tap water. Hence, it has been found that water in which functional glass is immersed has oxidation-reduction potential that is 1.7 - 2.0 times that of tap water that forms the base.

2.5 Surface tension of water in which functional glass is immersed

Fig. 4 shows the result of measurement of the variation of surface tension with temperature change in the range of about 25 - 70°C by means of the pendant drop method (6) by using a solution of coolant (concentration: 30%), pure water, and 100 cc each of these in which two "green" samples and two "black" samples of functional glass are immersed. The result of this measurement has shown that the surface tension of the coolant-based solutions is relatively lower than that of pure water-based liquids as a matter of course and it decreases with an increase in temperature. It can be seen from Fig. 4 that the surface tension of both the coolant-based solutions and pure water-based liquids has decreased by about 5 - 2% in proportion to a rise in temperature after the samples of functional glass have been immersed in them. Hence, it has been found that functional glass has characteristics that decrease the surface tension of water in which it is immersed by several percent. This phenomenon is judged to be caused by the aforesaid ultra-hydrophilic properties of functional glass.

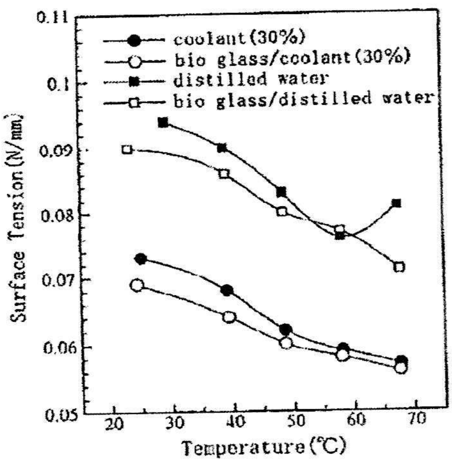

Fig. 4 Variation of Surface Tension of Bio Glass in Distilled Water and Coolant with Temperature Change

3. Influence when using functional glass in the cooling system of a diesel engine

3.1 Influence exerted on engine performance and exhaust gases

Functional glass was immersed in the cooling system for 24 hours, and its influence was checked with the sample engine shown in Table 5 by a partial load test at an engine

Table 5 Specifications of test engine

Remodeled Kubota MB	
Cavity configurations	Square
Combustion chamber	Direct Injection
Cycle	4
Number of cylinder	1
Bore & stroke	ϕ 100×150 mm
Displacement volume	1.178×10^{-3} m^3
Compression ratio	17.0/1
Output power	7.36kW/1000 rpm
Nozzle opening pressure	20.0 MPa
Injection timing	20.0° BTDC

revolution speed of 1000 rpm. With the cooling water inlet temperature set at 65±2°C, the engine performance, exhaust gas characteristics, and cylinder wall temperature were also measured at the same time. The result of measurement of the engine performance and exhaust gas characteristics is shown in Fig. 5.

As a result of this, it has been confirmed that the following effects are obtained by immersing functional glass in the cooling system, as compared with the ordinary condition (Base). With regard to he fuel consumption BSFC, reductions of 1.3 - 11.6% in all load ranges and a reduction of 5.1% on average could be obtained, and there were great reductions particularly in low load range and in high load range. The charging efficiency ηc rose by 1.5 - 3.0% in all load ranges, and the lubricating oil temperature T0 decreased by 4 - 12 K in all load ranges, and the exhaust gas temperature Teg decreased by 4 - 23 K in high load range. *BSCO* decreased by 7 - 54% at the load of Pme = 200 - 600 kPa, and *BSHC* decreased by 20 - 30% at the load of Pme = 200 - 600 kPa. *BSNOx* decreased by 3.7 - 14.7% at the load of Pme = 100 - 500 kPa. As can be seen from above, by using functional glass in the cooling system, effects were identified in reducing fuel consumption and improving exhaust gas characteristics.

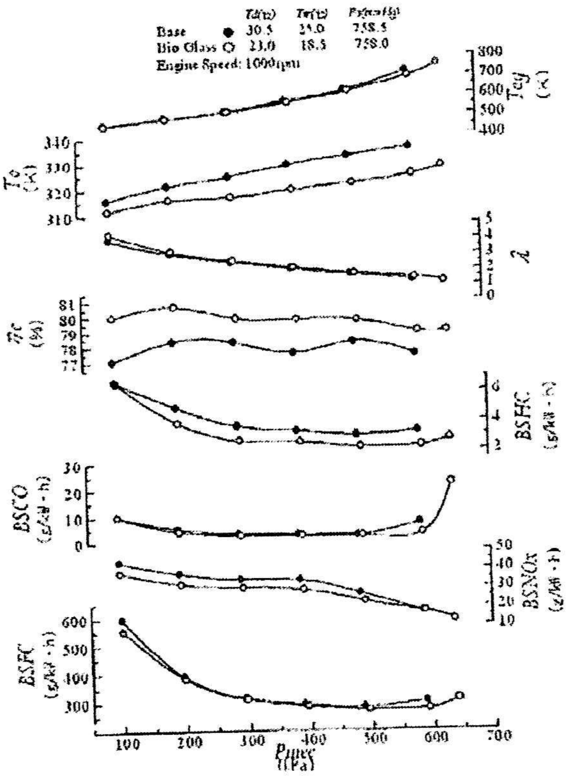

Fig. 5 Effect of "Bio Glass" on Engine Performance

3.2 Influence exerted on cylinder walls

The cylinder wall temperature was measured at 8 points, P1 through P8, in the axial direction at the exhaust side from TDC to around BDC simultaneously with the measurement for the engine performance test. The measurement of temperature was done by embedding seeds type thermocouples (K type, 1.6 mm in diameter) at a depth of 1.5 mm from the cylinder inner wall surface. As a result of this, hardly any change was observed in the temperature differences in P2 through P8, but P1 had the most noticeable temperature difference, and the result of temperature measurement for the load of P1 is shown in Fig. 7. This P1 is located near the piston ring at TDC, and with regard to the temperature difference between the base and functional glass, the latter decreased by 8 - 12°C at Pme = 400 - 600 kPa. This fact shows that functional glass gave a noticeable effect on the temperature decrease on the wall surface of the combustion chamber, thereby improving combustion as a result of increase in charging efficiency as mentioned above.

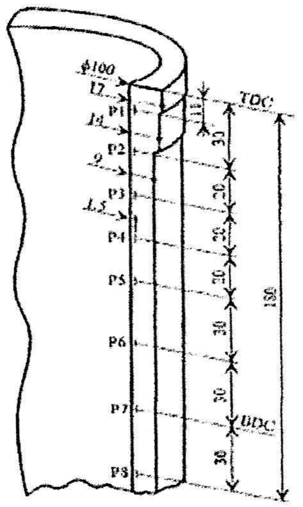

Fig. 6 Measured Points of Cylinder Wall

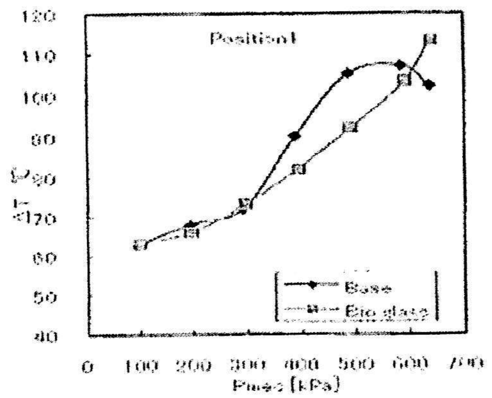

Fig. 7 Effect of "Bio Glass" on Cylinder Wall Temperature

4. Study

Functional glass has high far-infrared emissivity, ultra-hydrophilic properties, ion exchange characteristics, viscosity reduction characteristics, high oxidation-reduction potential, and reduction of surface tension, etc., and it is considered that among these reduction of surface tension contributed greatly to the decrease in temperature on the combustion chamber wall, thereby having a great influence on the increase in charging efficiency. Cooling in a water-cooled engine involves coexistence of forced convection heat transfer and subcooled boiling heat transfer [(7),(8)] and since it is a well-known fact that in these heat transfer areas the heat transfer rate increases[(9)] as a result of reduction in the surface tension of cooling water, it is considered that the decrease in temperature on the cylinder wall surface was caused by the reduction in the surface tension of cooling water. It is thought that these are the major factors that improved engine combustion and exhaust gases.

In addition, functional glass has characteristics that reduce viscosity and kinematic viscosity as well, and since the cooling system belongs to areas of turbulence, it is considered that the increase in the heat transfer rate was also caused by an increase in the velocity of flow of the cooling water around the combustion chamber. Moreover, functional glass is highly evaluated on the market in that knocking can also be reduced substantially in SI engines, especially in GDI engines.

5. Conclusion

(1) It has been made possible to clarify the various chemical characteristics of functional glass.

(2) It has been found that functional glass reduces the surface tension of cooling water, and as a result of an increase in thermal transfer rate, the charging efficiency is increased with the result that a lot of improvements can be made in fuel economy, engine performance, and exhaust gas characteristics.

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