9 Exhaust Emission Characteristics of a Diesel Engine with an Articulated Steel Forged Piston

Hyunchul Kim, Woo Kang, Byungchul Na, Hokil Lee
Power & IT Research Center of the Korea Automotive Tech. Institute
74 Yongjung-Ri, Pungse-Myun, Chonan 330-912, Korea

Abstract

In order meet the world's ever stringent environment regulations, the focus of this current research on diesel engines is to expressly reduce the size and enhance the power of engines simultaneously. Such requirements inherently increase the pressure of the combustion chamber. Under this high pressure, the operational pressure range of the current aluminum piston reaches to about the limit requiring a piston with higher operational pressure limit. The steel forged piston is under development as a potential replacement of the aluminum piston. In this study, in order to analyze the change of fuel consumption rate and emitted gas characteristics due to weights and heat transfer characteristics difference between the aluminum piston and the steel forged piston, fuel consumption rate and emitted gas characteristics are analyzed using a chassis dynamometer. The characteristics of emitted gas were analyzed through a CVS75 mode experiment. Results indicate that the characteristics of emitted gas of the articulated steel forged piston are similar to that of the aluminum alloy piston.

Keywords: Articulated Steel Forged Piston, Aluminum Alloy Piston, Chassis Dynamometer, CVS75 Mode, Emitted Gas Analyzer

1. Introduction

The size of diesel engines is becoming more compact with increased output[1] per unit weight according to the continuously growing customer's demand for the performance improvement of diesel vehicles. It is required to secure reliability for the pressure resistance of the essential components such as the piston due to the use of a charging system[2] and continuous increase in the internal pressure of the combustion chamber to increase the output power of diesel vehicles.

Therefore, since the existing aluminum alloy piston cannot respond to the requirements of the diesel engine for high-performance and high output power effectively, a steel forged piston was developed and is being applied to such diesel engines in advanced countries. Since Z. Dursunkaya et al. had studied the articulated steel forged piston in the early 90's, its rapid development was achieved by Peter Kemnitz[3] et al. through their studies on the optimum design of the mono steel forged piston suitable for high load diesel engines. This technology was commercialized by FM (Federal Mogul) n the USA and MAHLE in Germany. The steel forged piston for diesel engines is an essential component that is applicable to not only commercial vehicles of all sizes but also to 2 cycle engines and marine diesel engines. The manufacturers in advanced countries have developed and are producing steel forged pistons applicable to diesel engines, with particular care given to the aspects of price and reliability by developing an optimum combustion chamber using design data established through flow and combustion analysis, thermal stress analysis and dynamic analysis of the piston as well as various simulations and by achieving weight reduction through material development. This study performed comparison and analysis of the characteristics of the aluminum alloy piston, fuel economy and emitted gas with the chassis dynamometer for the steel forge piston prototype. This prototype was developed considering after installing an articulated steel forged piston in a diesel vehicle equipped with a 2.9L common rail engine in order to investigate the change in the fuel economy and emitted gas according to the piston weight and heat transfer characteristics obtained from steel and aluminum alloy pistons. The durability was verified through 30,000km of road driving.

2. Experimental Equipment and Method

2.1 Specifications of Vehicles for Experiment

The vehicle used in this study for the road driving test to verify the durability and reliability was a vehicle equipped with a common rail type 2.9L diesel engine and turbocharger, intercooler and EGR cooler. Table 1 shows the specifications of this vehicle.

2.2 Experimental Equipment and Method

Fig. 1 demonstrates the equipment used for the experimentation to compare the fuel economy and emitted gas between the aluminum alloy piston and articulated steel forged piston and Table 2 shows the major specifications of the experimental equipment. It is composed of a chassis dynamometer (AVL -RPL1220) and an emission gas spectrometer (PIERBURG-AMA2000C). The chassis dynamometer consists of a load absorbing device to simulate the road driving state and a flywheel to create inertial weight. The emitted gas sampling device designed to measure the actual quantity of emission gases continuously takes test samples with constant flow rate. During the vehicle test, a test sample was taken from the sampling bag after diluting the emitted gases from the test vehicle on the chassis dynamometer with constant amount of air by using the critical flow Venturi type constant volume sampling device (CFV: 20m^3/min). Of the diluted emitted gases, CO and CO_2 were analyzed with a Non-dispersive Infrared Analyzer (manufactured by Pierburg Co.), the NOx was analyzed with a Chemical Luminescence Analyzer (manufactured by Pierburg Co.), and the HC was analyzed with a Flame Ionization Analyzer (manufactured by Pierburg Co.). Then the emission quantity of the test pollutants per unit traveling distance (km) was calculated.

Table 1. Specifications of Vehicle

Description		Type
Engine	Type	Diesel, 4cycles
	Number of Cylinders	4 in series
	Type of Combustion Chamber	Re-Entrant
	Transmission Type	AT
	Fuel Injection Type	CRDI
	Total Displacement (cc)	2902
	Cylinder ID× Stroke (mm)	97.1×98
	Compression Ratio	19.3
	Compression Pressure (kg/cm^2-rpm)	30/200
	Max. Power Output (PS/rpm)	145/3800
	Max. Torque (Kg・m/rpm)	32.0/2000
	Fuel Economy (Km/ℓ)	10.0
Chassis	Overall Length (mm)	4,930
	Overall Width (mm)	1,895
	Overall Height (mm)	1,770
	Axle-to-Axle Distance (mm)	2,910
	Min. Ground Clearance (mm)	170
	Max. Speed (km/h)	188

Fig. 1. Photo of Experimental Equipment

Tble 2. Specifications of Experimental Equipment

Measuring Equipment and Devices and		Specifications
Chassis Dynamometer	Type	RPL1220
	Manufacturer	AVL(Austria)
	Roller Type and Diameter	Single Roll 48 inch (1220mm)

	Inertial Weight	1,000~12,000 LBS
	Max. Speed	200km/h
	Speed Error	±0.01%FS
	Torque Error	±0.1%FS
	Coast-down	Within 1 second
Emitted Gas Spectrometer	Type	AMA2000C
	Manufacturer	Pierburg (Germany)
	Sampling Device	CFV Type (Constant Volume Sampling Device)
	Accuracy of Temperature Gage	Within ±0.5℃
	Accuracy of Pressure Gage	Within ±0.25%
	Venturi Specification	20, 40, 60m^3/min
	Gases to be Analyzed	CO, CO_2, THC, NOx
	Analysis Range	CO (0~3,000ppm) CO_2 (0~20%) THC (0~10,000ppm) NOx (0~10,000ppm)

The particulate matters collected through the dilution tunnel (18 inches) were measured 2 times per each section. The Teflon coated filter (∅70mm) was used for the experiment. In order to exclude the interference of weight due to moisture and ultraviolet rays, the weight of all filters was measured after they were kept in a constant temperature and humidity device for 24 hours with the temperature and relative humidity maintained at 22±3℃ and 48±8%, respectively. The filter whose weight had been measured in the constant temperature and humidity device was installed in the filter hole of the dilution tunnel to collect the emitted gas passing through the tunnel.

The filter that collected the particulates was picked with a pincette so that the particulate collection part could not catch foreign substances and was kept in a schale wrapped with aluminum foil for 24 hours. Then the weight of the filter before and after particulate collection was measured to calculate the weight of the particulates using the weight difference.

Fig. 2 demonstrates the sketch of the emitted gas experiment on the chassis dynamometer. As an experiment method to evaluate the emission and purification performance, the CVS75 experiment mode for the emission of small vehicles currently used in Korea and USA was utilized. Fig. 3 shows the operation mode for the emission test. The CVS75 mode is the vehicle emission test method developed in California in the USA. It consists of 3 phases. The gas emission test is conducted by keeping the vehicle, which has been preliminarily driven, at constant temperature (25℃) and humidity for 12 hours. The Phase 1 (cold start stage) test is performed at average vehicle speed of 40.4km/h for 505 seconds and the Phase 2 (hot and stable stage) test is conducted at average vehicle speed of 25.6km/h for 867 seconds. After performing the above Phase 1 and Phase 2 tests, the vehicle is kept soaked at constant temperature (25℃) for 10 minutes. The Phase 3 test identical to the Phase 1 test is subsequently performed. Fig. 4 shows the vehicle being tested for emission on the chassis dynamometer.

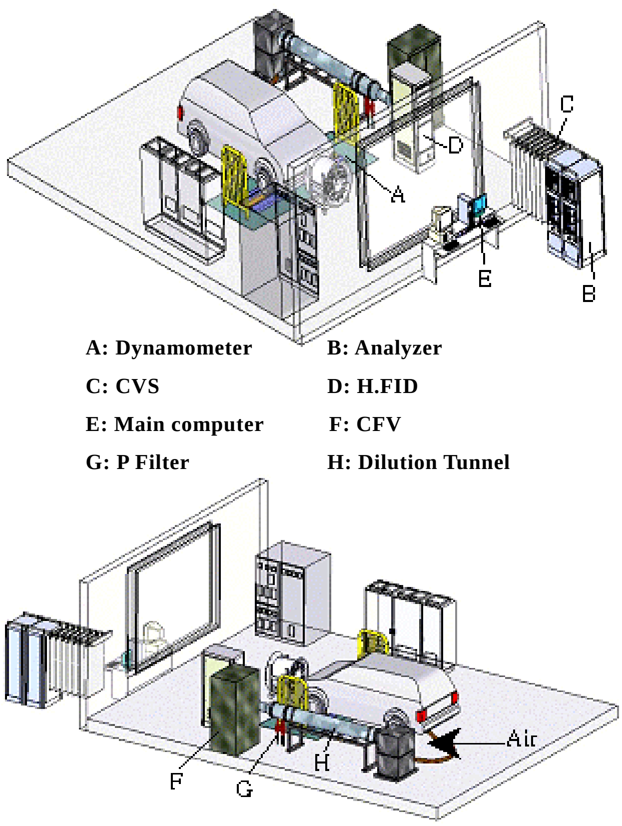

Fig. 2. Experimental Equipment for Vehicle Emission Test

After performing 4,000km of road traveling of the vehicle (displacement: 2.9L) equipped with a high speed direct injection engine having an aluminum alloy piston, the fuel economy and gas emission were measured with an emitted gas spectrometer. After replacing the aluminum alloy piston with the articulated steel forged piston, the road traveling was performed as far as 4,000km and 11,000km and then the fuel economy and gas emission were tested in the same manner as the test was performed for the vehicle with the aluminum alloy piston.

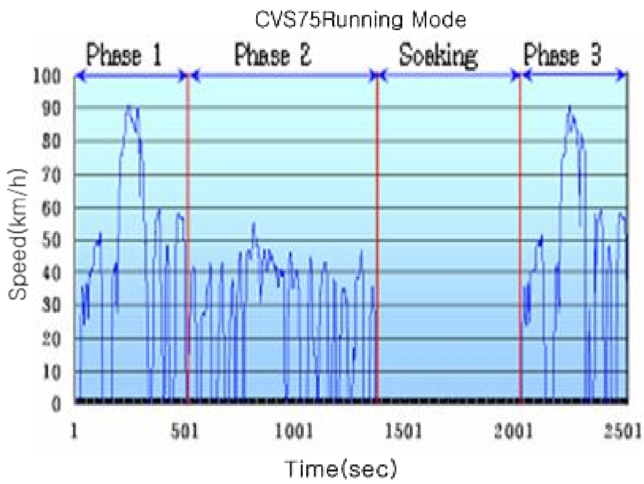

Fig. 3. CVS75 Operation Mode

Fig. 4. Emission Test of Target Vehicle

2.3 Experiment Results and Discussion

Figs.5 ~ 12 demonstrate the gas emission characteristics and fuel consumption rate per unit traveling distance (km) according to the operation mode for the emission tests with regard to the aluminum alloy piston and articulated steel forged piston, respectively.

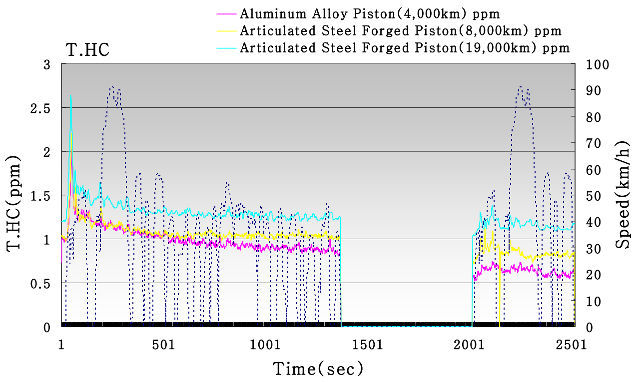

Fig. 5. Variation of THC versus CVS75 Mode

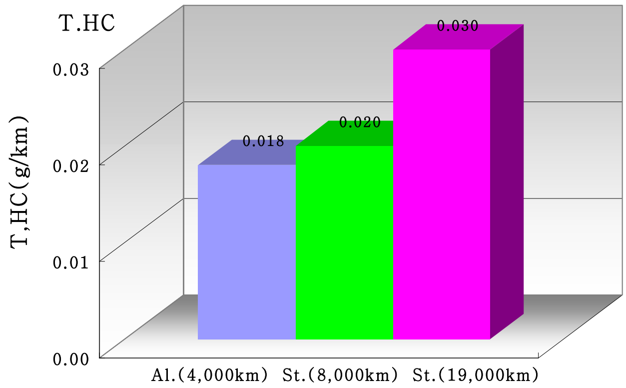

Fig. 6. Emission quantity of DHC

It can be seen from the emission characteristics of THC in Fig. 5 that the quantity of gas emission increased in Phase 1 of cold start (0 ~ 505 seconds) then it gradually decreased in Phase 2 of hot and stable stage (505~870 seconds). This is the general emission characteristics of the diesel engine in which the greater amount of THC was generated until the engine temperature increased up to the normal travel temperature (80~90℃) than when the engine temperature already reached the normal travel temperature. It can be seen that the amount of THC emission decreased as the engine temperature increased to the hot and stable stage of Phase 2 (505~870 seconds). It can be said that the THC emission characteristics for the aluminum alloy piston and articulated steel forged piston are identical throughout the entire engine RPM range. As can be seen from Fig. 7, the NOx has the characteristic that a greater quantity of NOx is generated as the combustion chambe temperature rises. Therefore, it is thought that since the thermal conductivity (144W/M・K) of the aluminum alloy piston is greater than that (39.35W/M・K) of the articulated steel forged piston, it will have influence on the increase of the combustion chamber temperature.

The piston temperature increase can be suppressed in two ways: through optimum design of cooling gallery of the piston and by increasing the quantity of oil fed to the piston. FM (Federal Mogul) in the USA, which commercialized the mono steel forged piston, obtained the calculation result through simulation that the quantity of oil 1.5 ~ 2 times as much as the oil fed to the existing aluminum alloy piston should be fed to the steel forged piston.
In this experiment, optimum design of the cooling gallery of the articulated steel forged piston was achieved. However, the experiment was performed with the quantity of oil fed to the steel forged piston being equal to the quantity of oil fed to the aluminum alloy piston.
Fig. 7 and Fig. 8 demonstrate that in the case of NOx emission characteristics and emission quantity per unit traveling distance, an aluminum alloy piston with the traveling distance of 4,000km and the articulated steel forged piston with the traveling distance of 8,000km demonstrated similar emission characteristics. However, in the case of the articulated steel forged piston with the traveling distance of 19,000km, the NOx emission quantity increased. Fig. 9 presents similar CO emission characteristics for both the aluminum alloy piston and the articulated steel forged piston. Fig. 10 demonstrates that there seemed to be a conspicuous difference in CO emission quantity between the cases of the aluminum alloy piston and the articulated steel forged piston. However, it is less than 0.02ppm, which is within the range of experimental error. Fig. 11 indicates that in the cases of the aluminum alloy piston with traveling distance of 4,000km and articulated steel forged piston with traveling distance of 19,000km, the identical quantities of PM was emitted. It can be said that in the case of the articulated steel forged piston with traveling distance of 8,000km the PM emission is almost equal since the difference in the PM emission quantity was 0.001g/km compared to the above case. Fig. 12 indicates that the fuel economy (travel distance per unit amount of fuel [km/ℓ]) is a little less in the case of the articulated steel forged piston (1,195g) than in the case of the aluminum alloy piston (760g) due to the difference in the weight.

3. Conclusion

This study obtained the following results of the experiment for the fuel economy and gas emission for the aluminum alloy piston and the articulated steel forged piston on the chassis dynamometer by measuring and performing a comparison analysis of the values of the fuel economy and gas emission.

1) Fuel economy and emission analysis were performed through the CVS75 mode experiment on the chassis dynamometer by installing the developed articulated steel forged piston on a diesel vehicle for testing.
2) The emission characteristics in the case of the articulated steel forged piston according to the CVS75 mode experiment were similar to that of the aluminum alloy piston.
3) Similar results concerning the fuel economy were obtained by performing the comparison analysis of the fuel economy for the aluminum alloy piston and articulated steel forged piston on the chassis dynamometer.
4) The reliability of the articulated steel forged piston was verified by performing a 30,000km durability test.
5) It is proposed that the weight of the articulated steel forged piston and mono steel forged piston be reduced through optimum design and material development.

References

(1) Choi. Kyu Hoon, "What will be the Future of HSDI Diesel Engines", KSAE, Vol. 23, NO. 1, pp. 43-53, 2001.
(2) Akira Numata, Yoshinori Nagae, “Increase of Thermal Efficiency and Reduction of NOx Emissions in DI Diesel Engines", Mitsubishi Heavy Industries, Ltd. Technical Review Vol. 38 No. 3 (Oct. 2001).
(3) Peter Kemnitz, Olaf Maier, Palph Klein, "Monotherm, a New Forged Steel Piston Design for Highly Loaded Diesel Engines", SAE 2000-01-0924, 2000.
(4) Elsbett, Klaus, Guenter, Ludwig, Behrens, Michael, "Ferrum Piston for Diesel Engines-A two-piece optimized Articulated Piston Design", SAE Special Publications, pp. 79-85, 1985.
(5) Jose M. Martins Leites, Roberto C. De Camargo, “Articulated Piston Cooling Optimization", SAE 930276, 1993.
(6) M. Konno, S. Kajitani, M. Oguma, T. Lwase, K. I. Shima, "NO Emission Characteristics of a CI Engine Fueled with Neat Dimethyl Ether", SAE 1999-01-1116, 1999.

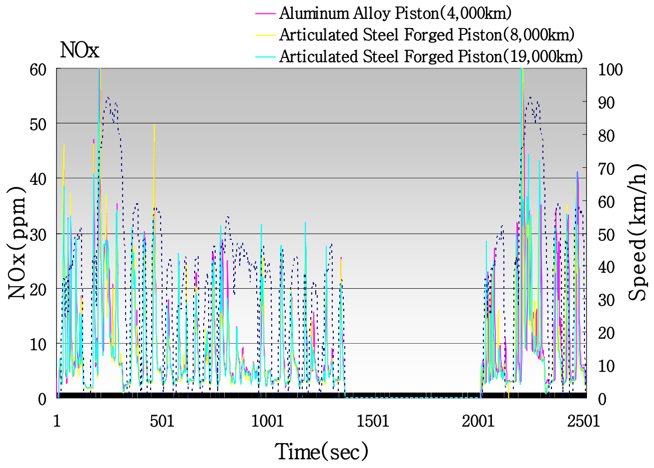

Fig. 7. Variation of NOx versus CVS75 Mode

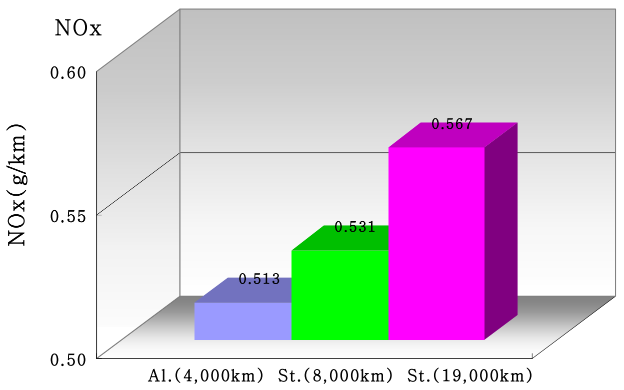

Fig. 8. Emission Quantity of NO

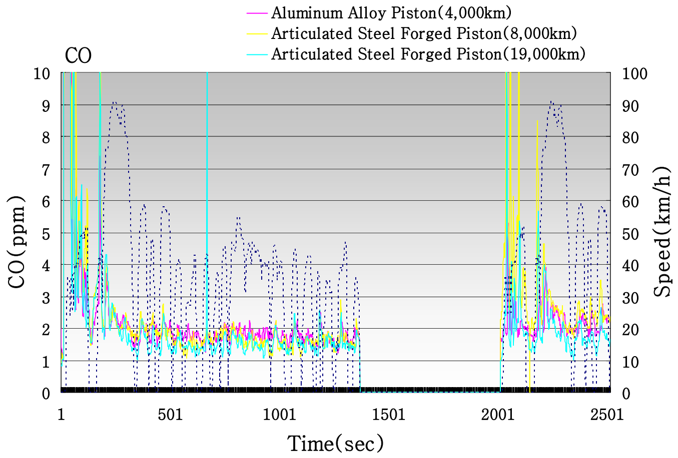

Fig. 9. Variation of CO versus CVS75 Mode

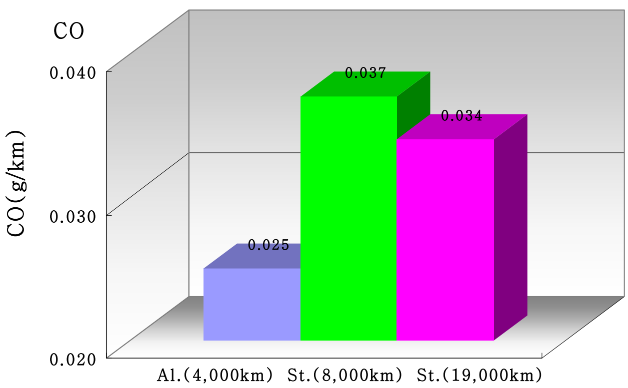

Fig. 10. Emission Quantity of CO

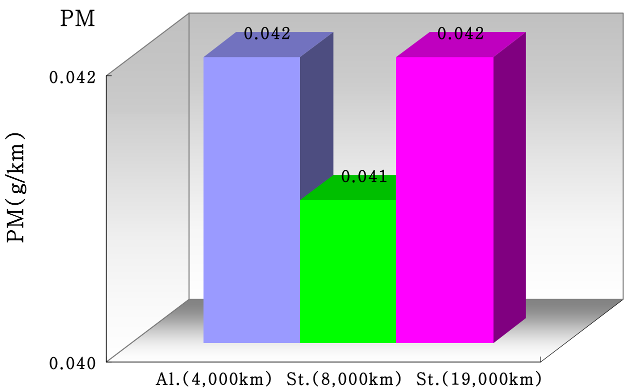

Fig. 11. Emission Quantity of PM

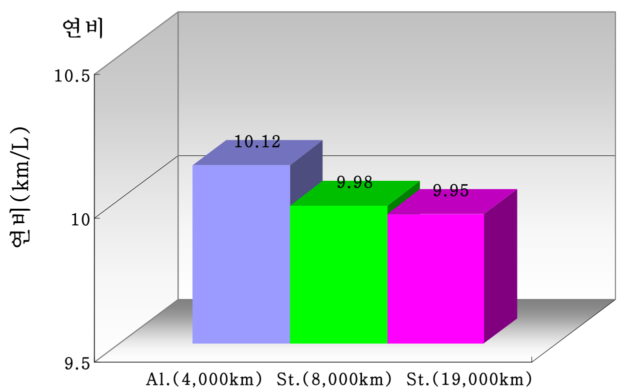

Fig. 12. Fuel Consumption of AL Piston and ST piston