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Development of Meshwork DPF Catalyst for Fuel Economy Improvement

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ABSTRACT

Diesel particulate filters (DPFs) are an essential aftertreatment component for reducing the PM emissions of diesel engine vehicles. Installation of a DPF can achieve high filtration efficiency, but PM filtration also causes a high pressure drop due to deep bed filtration. Consequently, periodic PM regeneration is necessary to keep a low pressure drop, but this causes significant deterioration in fuel efficiency. Improving the efficiency of PM regeneration and keeping the pressure drop low are major challenges faced by DPF manufacturers in meeting future CO_2 emissions regulations. This paper presents a novel morphological catalyst layer for DPFs, which is located in the surface of the inlet DPF channels and has been formed into a highly porous and three-dimensional meshwork shape. These features enhanced not only the prevention of deep bed filtration to reduce the pressure drop, but also the soot-catalyst contact for a faster PM regeneration rate. Cold flow and transient tests were used to evaluate the pressure drop, while passive and active regeneration conditions were used to investigate PM regeneration. The improvement in fuel economy was also estimated. This novel catalyst showed significant low transient pressure drop. The meshwork catalyst provided almost the same pressure drop compared to a bare substrate without PM loading, as well as a low pressure drop with PM loading. Moreover, the achievement of a higher PM regeneration rate was confirmed when measured under active regeneration conditions. Additionally, this catalyst improved fuel economy remarkably compared to a conventional DPF under PM loading and regeneration cycles.

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INTRODUCTION

Given its high torque at low speeds, high reliability, and good fuel economy, the diesel engine is a promising technology not only for on-road utilities like passenger cars and trucks, but also for off-road utilities in the construction and agricultural sectors. On the other hand, diesel exhaust contains PM and NOx, which are recognized as one of major causes of air pollution. However, to satisfy the newer more stringent emissions regulations, such as Euro 6 in Europe, Tier3 in the U.S., and the post new long-term regulation in Japan, advanced exhaust aftertreatment systems such as DPF for PM, SCR, and LNT for NOx are required. These catalytic converters are being used successfully and have decreased harmful emissions drastically.

The DPF is an essential aftertreatment component for diesel engine vehicles because of its high PM filtration efficiency. However, PM filtration causes a high pressure drop, so periodic regeneration is needed. Periodic regeneration consists of an increase in the exhaust gas temperature via post injections and/or exhaust fuel injection in order to combust the loaded PM and keep pressure drop low. For that reason, repeated PM loading and regeneration are indispensable to characteristic of DPF operation.

Fuel economy standards and emissions regulations are also becoming more stringent. CO_2 emissions standards for passenger vehicles were initially introduced in Europe in 2009, with a 120 g/km fleet average CO_2 standard stipulated by 2012. A 95 g/km CO_2 standard is now targeted to go into effect by 2020. The U.S. is also targeting a 97 g/km CO2 standard for passenger cars by 2025 [1]. These regulatory trends indicate that the fuel economy of vehicles has clearly become an important point for future emissions regulations.

DPFs have two main problems when it comes to fuel economy: the pressure drop during soot loading, and regeneration. Filtration during soot loading is divided into two modes: deep bed mode and cake mode. At the beginning of soot loading, deep bed filtration mode occurs due to penetration of soot particles into the DPF substrate pores. After initial soot loading, additional soot particles are deposited on the soot layer that was already loaded on the surface of substrate channels. This deposited soot layer then acts as a filtration layer and becomes thicker. This phenomenon is called the cake filtration mode. The pressure drop increases rapidly during deep bed filtration mode due to the decrease in substrate wall permeability [2]. Various membrane approaches have already been proposed to overcome this rapid increase in pressure drop during deep bed filtration [3, 4, 5, 6, 7, 8, 9, 10]. For example, a membrane which has a different pore structure than the DPF substrate is located in the inlet channel surface and has small pores. This membrane provides low transient pressure drop and good filtration efficiency. It also improves pressure drop hysteresis because of accelerated soot cake formation. However, applying a coating catalyst on the DPF substrate with this membrane is relatively difficult because the membrane pores become clogged with catalyst particles, causing a high pressure drop.

In addition, there are two soot regeneration methods: active and passive regeneration. In the active regeneration process, soot is regenerated by oxygen predominantly at a temperature of over approximate 500 degrees Celsius. Active regeneration needs fuel injection in order to elevate the exhaust gas to a high temperature. However, it also causes a remarkable deterioration in fuel economy. Passive regeneration requires large amounts of NO_2 in relation to the soot mass to promote the chemical reaction between carbon and NO_2 at a relatively low exhaust temperature. Catalyst technology also plays an important role in the soot burning process. A catalyst washcoat deposited in or on the DPF substrate promotes active and passive PM regeneration. Many factors affect PM regeneration performance because of the complexity of PM regeneration as a solid-solid-gas reaction. One of the critical factors is catalyst-soot contact. While the tight contact mode generally provides effective catalytic performance, in practical use the majority of the contact mode is loose contact. In order to address the poor soot-catalyst contact problem, the morphology of the catalytic particles was studied by many researchers [11, 12, 13, 14, 15, 16]. Catalysts with special morphology, such as fibers, nanometrics, and core-shells, have been described and they enhanced the catalytic performance because of an increase in the number of contact points. Despite these positive results, most studies remained pure laboratory work and did not note the relation to comprehensive DPF performance.

The demand for improvement of both transient pressure drop and PM regeneration efficiency led to the development of this meshwork DPF catalyst, which simultaneously unites the functions of decreased deep bed filtration and increased soot-catalyst contact to improve the fuel economy performance of the DPF. Furthermore, this meshwork catalyst also provides superior filtration efficiency. In this paper, evaluation results from both the laboratory and the engine-bench will be presented to describe the basic catalyst performance and to demonstrate its advantages compared to conventional catalysts. In addition, the improvement in fuel economy under PM loading and the regeneration cycle will also be estimated.

Concept

The sharp increase in pressure drop during the initial soot loading period is a well-known fact. This behavior is called deep bed filtration, and is caused by soot particles penetrating into the DPF substrate and clogging the wall pores. In order to solve this problem, a small pore structure and a high porosity structure is an effective means of achieving both a low pressure drop and good mechanical strength. Consequently, dual-layer membrane substrate approaches were proposed. A surface layer that has small pore diameters and high porosity provides high filtration efficiency and a lower pressure drop during soot loading, while also providing DPF substrate functions that maintain the structural strength and ensure heat capacity. Although this surface layer achieved good suppression of the sharp increase in the pressure drop during the initial period of soot loading, the majority of the soot remained on the surface layer. Conventional DPF catalysts were coated inside the substrate, and catalytic soot regeneration performance might therefore have decreased due to the lack of soot-catalyst contact.

The soot-catalyst contact is a very important factor in catalytic soot regeneration. In general, the soot oxidation rate of tight contact that is prepared by mixing soot together with the catalyst in a ball mill is much higher than that of loose contact that is prepared by mixing it with a spatula. The soot-catalyst contact that occurs during practical use is most similar to the loose contact condition making it difficult to apply the results from tight contact to real conditions. Catalyst morphology control is one of the most effective methods for overcoming this problem. Some researchers reported that catalyst morphology enhanced soot oxidation under the loose contact condition because of the increased amount of soot-catalyst contact.

The meshwork catalyst achieves both a low pressure drop and high soot oxidation performance, improving the total fuel efficiency of DPF operation. This meshwork structure consists of a catalyzed three-dimensional network positioned on the inlet channel surface. These unique features enhance not only the inhibition of deep bed filtration, but also the soot oxidation by surrounding the soot particles three dimensionally and increasing the amount of soot-catalyst contact.

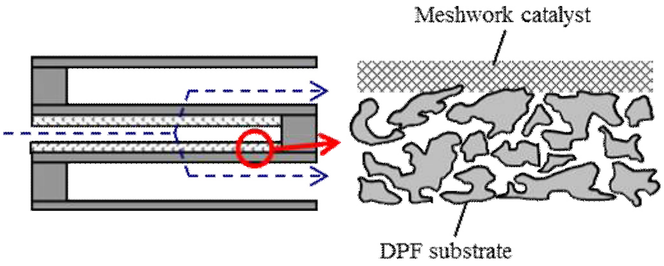

Figure 1. Meshwork catalyst concept.

EXPERIMENTAL

Catalysts

This meshwork catalyst was then compared to a conventional DPF catalyst to demonstrate how this new type of catalyst improves the vehicle fuel economy. All samples were prepared with SiC-DPF filters. Detailed DPF specifications are summarized in Table 1. Both samples were prepared using the same DPF specifications. In the engine bench test a DOC was used in front of the DPF samples. The DOC was a conventional one with PGM loading of Pt = 56.6 g/ft^3 and Pd = 28.3 g/ft^3.

The amount of PGM loading for both the meshwork and conventional catalysts was the same. Pt loading was 17 g/ft^3 and Pd loading was 8.5 g/ft^3. Table 2 shows the detailed catalyst specifications.

Table 1. DPF substrate specifications.

Substrate material	Silicon Carbide
Size	160 mmD × 135 mmL (2.7 L)
Cell structure	12 mil / 300 cpsi
Cell symmetry	asymmetry
Mean pore size	11 µm
Porosity	42%

Table 2. DPF catalyst specifications.

Pt load amount	17 g/ft^3
Pd load amount	8.5 g/ft^3

Table 3. DOC catalyst specifications

Pt load amount	56.6 g/ft^3
Pd load amount	28.3 g/ft^3

Laboratory Evaluation

Cold flow tests were performed using a flow bench in order to evaluate the increase in the pressure drop due to the catalyst coating. The pressure drop of the catalyzed DPF was evaluated at various flow rates. The flow temperature was maintained at 25 degrees Celsius and humidity was maintained at 65%.

Engine Bench Evaluation

Test Cell Setup

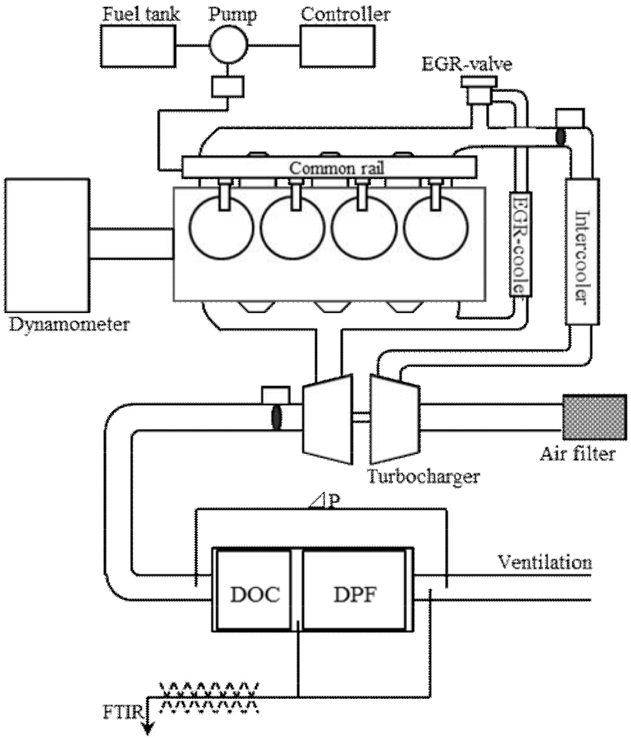

Figure 2. Test cell schematic.

Figure 2 illustrates the test cell layout, which shows the engine, dynamometer, and instrumentation, and other details. The engine used for this test was an in-line 4-cylinder 2.9 L common rail direct-injection turbocharged diesel engine. The base engine has a rated power of 106 kW. Engine-out NOx in WLTC was about 0.21 g/km. A smoke meter (GSM-10EA, from Sokken) was used for accurate estimation of the soot loading amount. A gas analyzer (Horiba MEXA-7100D) was used to measure CO, HC, NO/NOx, O_2 and CO_2. The measuring points were set at the inlet and outlet of the DPF. A manometer (PZ-77, from Sokken) was used to measure the pressure drop behavior during soot loading and regeneration. The measuring points of the differential pressure before and after the aftertreatment system included the DOC and DPF.

Soot Loading

Soot loading was performed under steady state conditions. Table 4 shows these test conditions in detail. The DOC was located in front of the DPF during soot loading in order to reproduce practical soot properties. In the soot regeneration test, soot was loaded up to 5 g/L. After loading, the amount of soot was weighed under dry conditions at 250 degrees Celsius. Soot loading rate were accelerated in order to reduce test time.

Table 4. Soot loading conditions.

Engine speed	2000 rpm
Torque	50 Nm
Intake air mass	30 g/s
Temperature	300 deg. C
Soot loading rate	6.5 g/h

Soot Regeneration

Active and passive regeneration tests were performed to evaluate the soot regeneration rate under different modes. The active regeneration evaluation was performed by exposing the catalysts to a steady state at 300 degrees Celsius and then applying a temperature ramp from 300 to 580 degrees Celsius. After ramping up, the inlet DPF temperature was held steady for 5 minutes. The passive regeneration evaluation was performed by using a temperature ramp from 300 to 400 degrees Celsius and then holding the temperature steady for 1 hour. In these experiments, the regeneration rate was calculated as the total amount of soot burn divided by the regeneration time.

Table 5. Active regeneration conditions.

Engine speed	2200 rpm
Torque	65 Nm
Intake air mass	60 g/s
DPF inlet temperature	580 deg. C

Table 6. Passive regeneration conditions

Engine speed	2000 rpm
Torque	80 Nm
Intake air mass	50 g/s
DPF inlet temperature	400 deg. C

Drop to Idle

A drop-to-idle test was performed to evaluate the thermal shock durability of the meshwork catalyst. Thermocouples were placed in certain locations on the DPF substrate as shown in Figure 3. The sample inlet temperature was ramped up from 300 to 700 degrees Celsius in 30 seconds before dropping back to idle. Figure 4 shows these test conditions in more detail. A repeated cold flow test and regeneration test were performed to evaluate the thermal durability.

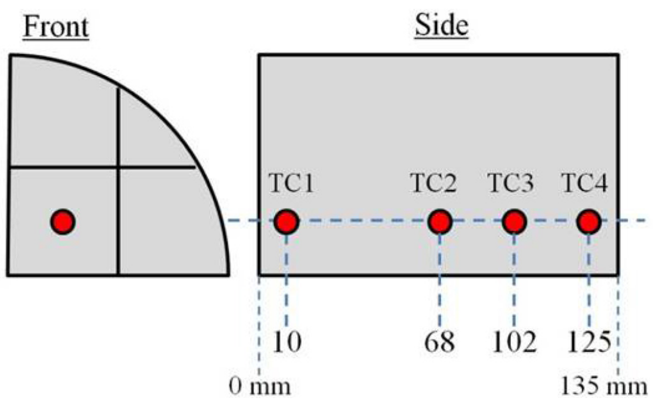

Figure 3. Thermocouple positions.

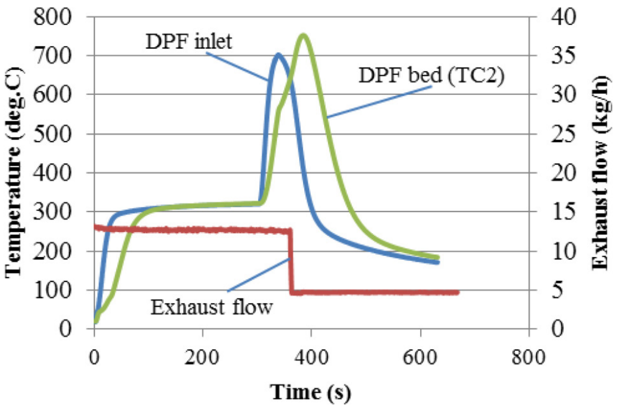

Figure 4. Drop to idle test conditions.

Fuel Economy Evaluation

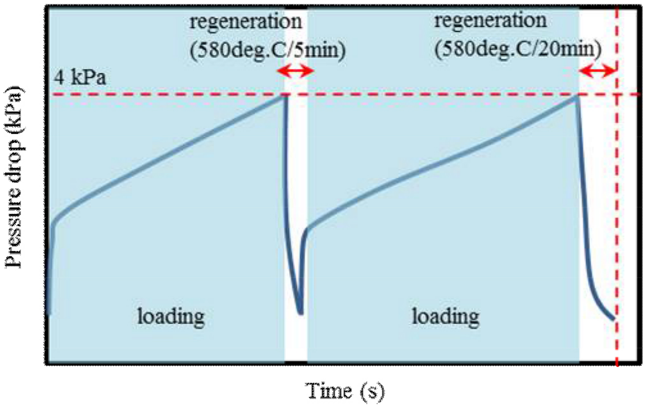

Figure 5. Schematic of one cycle of soot loading and regeneration.

The fuel economy evaluation was conducted by performing soot loading and regeneration cycles. Figure 5 shows a basis cycle for fuel economy evaluation. This basis cycle consists of 2 soot loadings and 2 regenerations. In order to introduce two kinds of regeneration pattern, that is partial and complete, different regeneration conditions were set in a basis cycle. DPF samples continued soot loading until the pressure drop reached 4.0 kPa. After soot loading, the soot was regenerated at 580 degrees Celsius for 5 minutes. The soot was then reloaded from the state of partial regeneration in the previous process. Once the pressure drop reached 4.0 kPa again, the regeneration process was conducted at 580 degrees Celsius for 20 minutes in order to remove almost the entire amount of soot. The soot loading and regeneration process described here was regarded as one cycle. Fuel economy was then evaluated by estimating the total amount of fuel injection based on that of the one-cycle test.

Chassis Dynamometer Evaluation

Setup

The test vehicle was a standard EU5 vehicle with a 3.0 L diesel engine. The DPF samples with DOC were located in the under floor position. The vehicle was tested on a chassis dynamometer with a CVS system for bag analysis (Horiba MEXA-ONE). The particle number after the aftertreatment system was measured using a MEXA-2100SPCS, while a MEXA-1170SX was used in this system to measure the gaseous emission components. Figure 6 shows a schematic diagram of the chassis dynamometer test system.

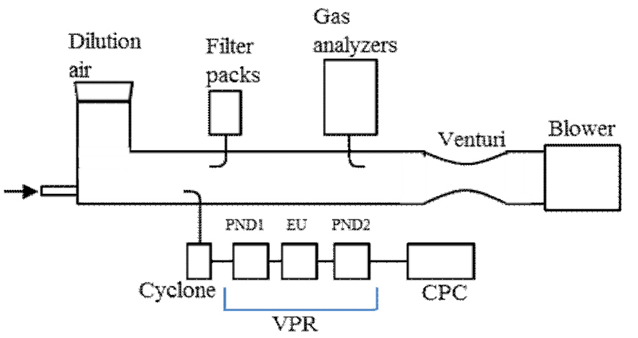

Figure 6. Schematic of chassis dynamometer test.

Filtration Efficiency

The filtration efficiency evaluation was performed under the WLTC class 3 test cycle. The DPF samples were evaluated in the under floor position of the vehicle. The WLTC class3 test cycle consists of four parts: low, medium, high, and extra high. Pre-conditioning that includes one WLTC cycle. After that, soaking time of more than 6 hours was conducted before the evaluation test was carried out.

RESULTS

Catalyst Morphology Observation

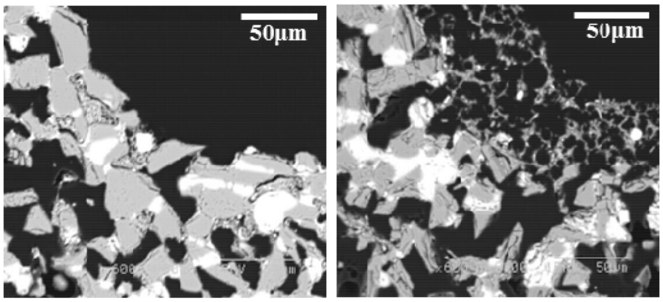

Figure 7. SEM images of catalyst cross section. (Left: reference, right: meshwork)

FESEM direct observation of the coated meshwork DPF catalyst was performed. The overhead and cross-sectional views of the meshwork catalyst are shown in Figures 7 and 8. These figures show the morphology of the meshwork catalyst, which is a three-dimensional pore network with particular inorganic materials and a highly porous structure. The catalyst remained on the inlet DPF channels and scarcely intruded into the substrate pores.

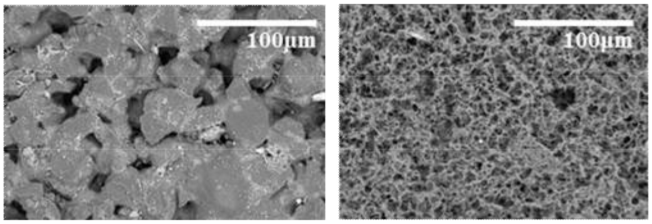

Figure 8. SEM images of catalyst on inlet channel surface. (Left: reference, right: meshwork)

Pressure Drop Evaluation

The initial pressure drop of the catalyst samples was measured on a cold flow bench. A meshwork catalyst sample, conventional catalyst sample, and a bare DPF sample were prepared for the purpose of comparing them. Figure 9 shows the evaluation results. In comparison to the pressure drop measured on the bare DPF, the pressure of the meshwork catalyst increased by 0.9 kPa and the pressure of the conventional sample increased by 0.3 kPa. However, there is little difference in the pressures of the meshwork and conventional catalysts. These results indicate that the meshwork catalyst has sufficient permeability and that there is little clogging of the surface DPF substrate pores that causes a drastic increase in the pressure drop.

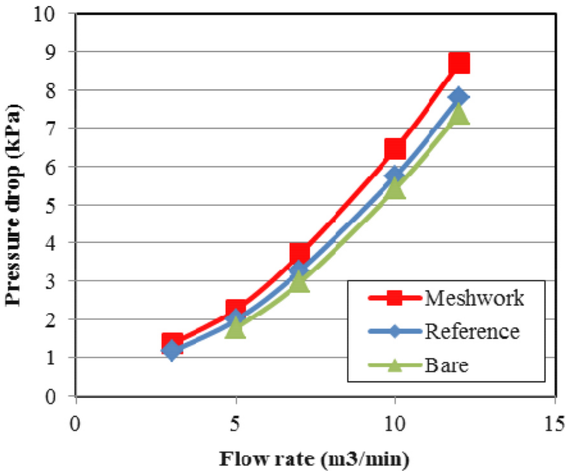

Figure 9. Pressure drop evaluation results.

Soot Loading Evaluation

Figure 10 shows the effectiveness of the meshwork catalyst at suppressing the increase in the pressure drop during soot loading. Although the initial pressure drop of all the samples was almost the same, the meshwork DPF catalyst was able to suppress the rapid increase in the pressure drop. On the other hand, the pressure drop of the conventional catalyst increased by 2.4 kPa as soon as filtration began. After the deep filtration mode, the pressure drop of both samples increased in parallel because of the transition to cake filtration mode. The pressure drop of the meshwork DPF catalyst sample was reduced by 32% compared to the conventional catalyst. These results indicate that the meshwork DPF catalyst can inhibit deep bed filtration into the substrate surface and also reduce the rapid pressure drop increase.

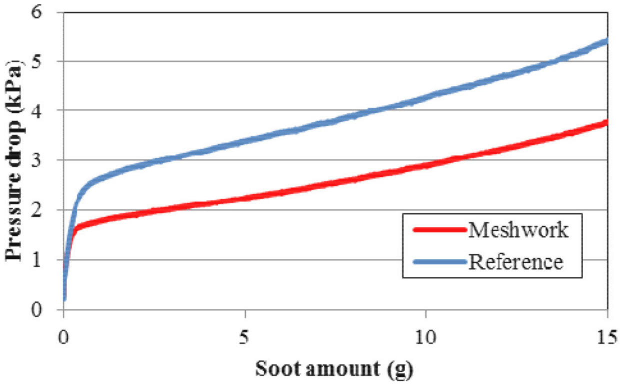

Figure 10. Pressure drop during soot loading.

Filtration Efficiency Evaluation

The filtration efficiency of the meshwork catalyst and the conventional catalyst were evaluated under WLTC conditions. Figure 11 illustrates the PN emissions behavior in comparison to a reference sample under these WLTC conditions. In the case of the reference sample, particles were mostly emitted at cold-start and then moderate particles emissions were recorded from the medium to extra high speed part compared to the cold start. On the other hand, PN emissions from the meshwork catalyst were always moderate compared to that of the reference sample. Small PN emission peaks were detected during cold-start, the high speed part, and the extra high speed part. The PN emissions trends of the reference sample indicated that reference sample could not form soot cake in pre-conditioning and cold start part. A soot layer formed by bed filtration could reduce and saturate PN emissions after cold start part. Meanwhile, the PN emissions trends of the meshwork catalyst indicated that pre-conditioning formed a soot layer on meshwork catalyst and effectively reduce PN emissions from cold start. In high and extra high speed part, increase of PN emissions occurred due to the fragileness of soot layer and good passive regeneration performance compared to the reference. Figure 12 shows PN emissions during WLTC. Compared to the evaluation result of the reference, meshwork catalyst can improve PN emissions by 68%. This improvement of filtration efficiency comes from its position and morphology. The meshwork catalyst might promote inhibition of soot particle penetration into the DPF substrate wall effectively.

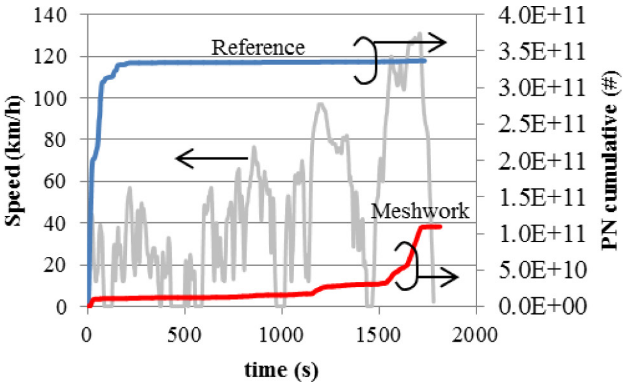

Figure 11. PN cumulative during WLTC.

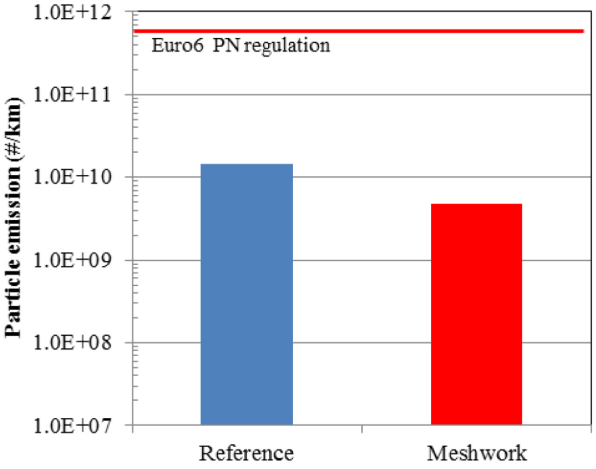

Figure 12. Particulate number emissions during WLTC.

Soot Regeneration Evaluation

The active and passive soot regeneration rates were evaluated using the meshwork and conventional DPF catalysts. Figure 13 shows the active soot regeneration rates. The regeneration rate of the meshwork DPF catalyst was 36% higher than the conventional catalyst.

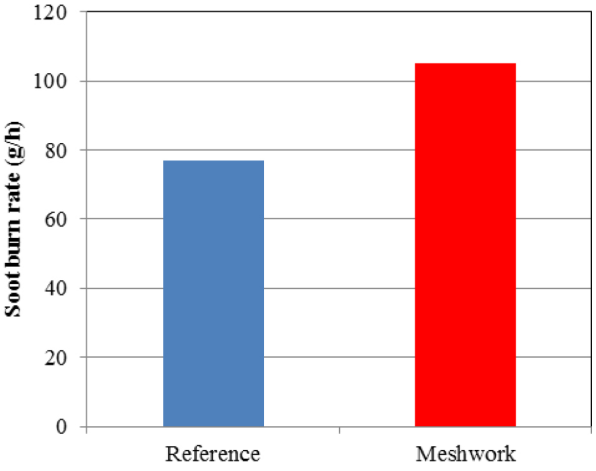

Figure 13. Comparison of active regeneration rates.

Figure 14 shows the evaluation results of the passive soot regeneration rates. The passive regeneration rate of the meshwork catalyst was higher by 4 g/h in comparison to the conventional catalyst. Figure 15 shows the pressure drop during the passive regeneration evaluation test. The pressure drop from both samples continued to decrease at a constant rate during passive regeneration. However, the difference in the pressure drop at the end of the test widened from 2 kPa to 4 kPa. The meshwork catalyst promotes active and passive regeneration because of its location, structure, and the high PGM concentration per soot contact area, which promotes adjacency between the soot particles, oxygen and the catalytic active sites that generate NO_2 three-dimensionally.

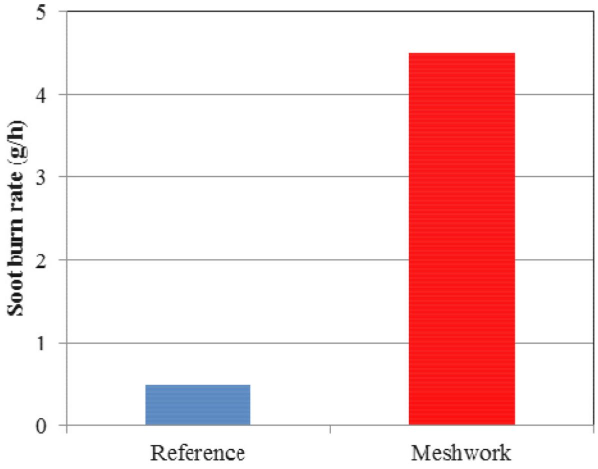

Figure 14. Comparison of passive regeneration rates.

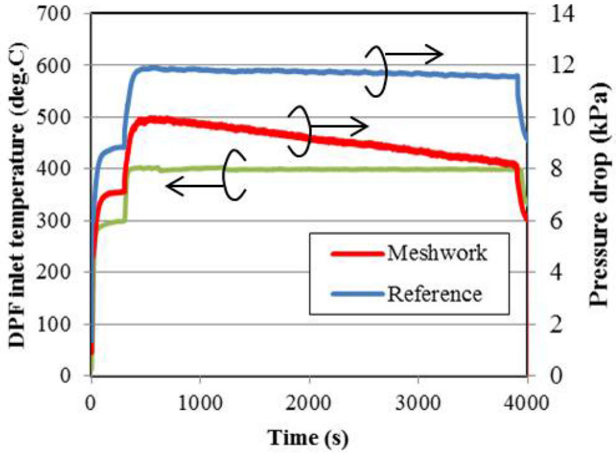

Figure 15. Pressure drop behavior during passive regeneration

Thermal Shock Durability Evaluation

In order to evaluate the durability of the meshwork catalyst during practical use, thermal shock durability with drop-to-idle tests were performed. In these tests, the temperature distributions in drop-to-idle and the deterioration tendency of the structural durability were both evaluated. Figure 16 shows the temperature gradients of the meshwork and conventional catalysts in the drop-to-idle tests. The test results from the meshwork catalyst show that the temperatures at TC3 and TC4 notably increased compared to the conventional catalyst, while the temperatures at TC1 and TC2 were almost the same as the DPF inlet temperature. On the other hand, the temperature of the reference sample did not exceed 700 degrees Celsius, which is the maximum DPF inlet temperature. TC1 and TC2 were almost the same as the DPF inlet temperature, but the temperatures of TC3 and TC4 gradually decreased due to the slight soot oxidation and high heat capacity of the DPF substrate. Compared to active regeneration test, the maximum temperature of meshwork catalyst were at least 300 degrees Celsius higher in short time. This phenomenon is likely attributed to the promotion of soot-catalyst contact by meshwork catalyst morphology. From the points of view of maximum temperature and temperature rising rate, drop-to-idle test condition was more severe than active regeneration test for thermal shock.

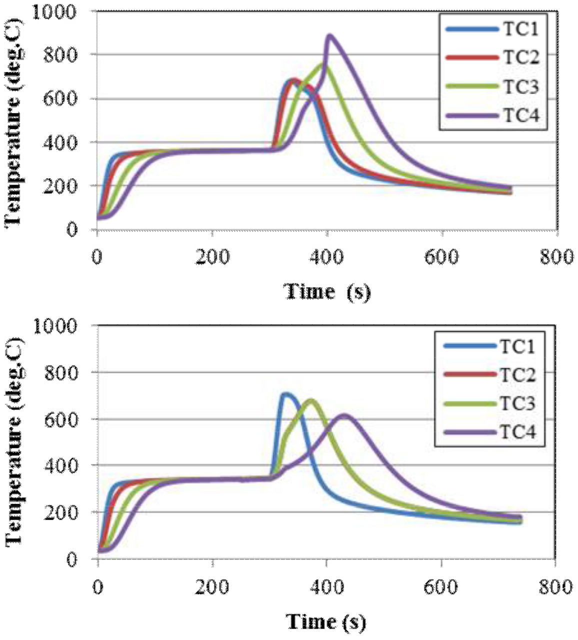

Figure 16. Sample Temperature Gradients during drop to idle tests. (Upper graph: meshwork catalyst, lower graph: conventional reference catalyst.)

Figure 17 shows the cold flow evaluation results after repeating the drop-to-idle tests. The pressure drop seen in the thermal shocked samples was practically unchanged in comparison to that of the fresh sample. The meshwork catalyst is highly porous compared to the DPF substrate in order to suppress any additional increase in the pressure drop. Porous materials generally have low mechanical strength and it is possible for them to peal, transform, and shrink, or otherwise deform. This will cause a pressure increase or decrease compared to the bare substrate. These results from the cold flow evaluation demonstrate that the meshwork catalyst maintains its unique structure and has sufficient durability.

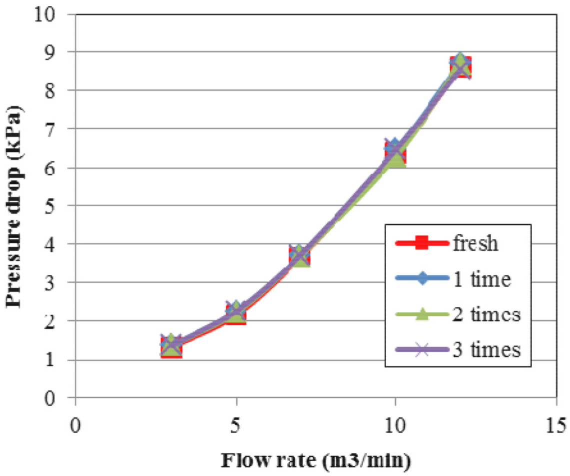

Figure 17. Cold flow test results.

Figure 18 shows PN emissions during WLTC before and after repeating the drop-to-idle tests. In spite of repeating high temperature over 800 degrees Celsius, meshwork catalyst can keep filtration performance and PN emissions were unchanged compared to that of fresh sample. These results demonstrate that thermal shock by drop-to-idle does not affect the filtration performance of meshwork catalyst.

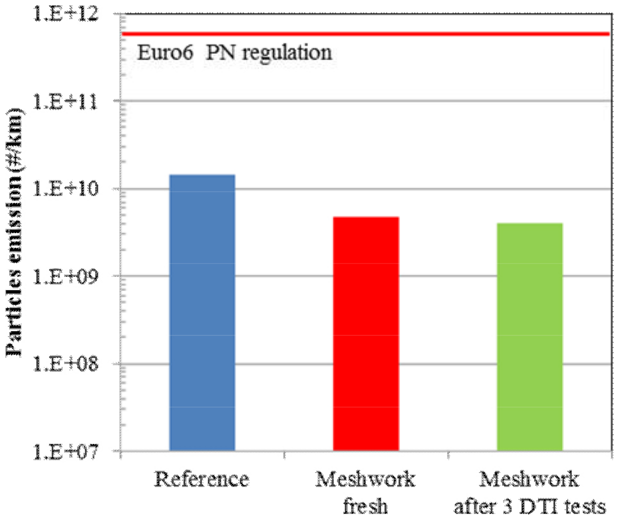

Figure 18. Particular emissions during WLTC before and after repeating drop-to-idle tests.

Figure 19 shows SEM images of a sample before and after the thermal shock durability test at TC4 position. In spite of the thermal shock with a rapid rise in temperature to over 700 degrees Celsius, the morphology of the meshwork catalyst showed almost no difference in appearance and catalyst thickness. Binary image analysis, which was performed to estimate the porosity, shows almost the same porosity both before and after the repeated thermal shocks. These evaluation results demonstrated that the meshwork catalyst has no fatal defects in relation to the thermal shock during practical use or severe thermal shock in comparison to the reference sample.

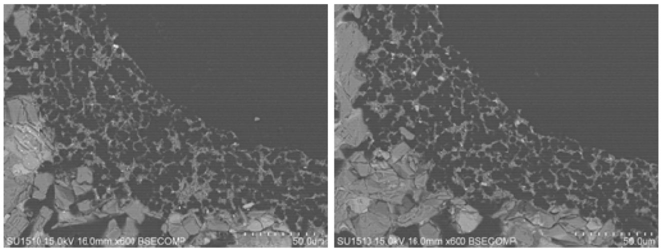

Figure 19. Cross section SEM images (Left: fresh, right: aged).

Fuel Economy Evaluation

The effect of the meshwork catalyst on the fuel economy was evaluated by adding together the fuel consumption during the soot loading and regeneration processes. Once again, the meshwork catalyst was compared to a conventional catalyst used as a reference. The fuel consumption during a regeneration cycle was calculated to make this estimate. Figure 20 shows the total time of one test cycle. The total testing time of the meshwork catalyst was 67 minutes longer than that of the reference catalyst. During the initial soot loading, the meshwork catalyst suppressed the sharp increase in pressure drop effectively because it inhibited the deep bed filtration better than the reference sample. The pressure drop of the soot reloading point depends on the performance of the soot regeneration rate. As described previously, the meshwork catalyst could reload soot with a lower drop in pressure because of its good active regeneration performance. On the other hand, the reference sample reloaded soot and then showed a higher drop in pressure. These results demonstrate that the strong suppression of deep bed filtration and high soot regeneration performance can lead to the extension of the soot regeneration interval.

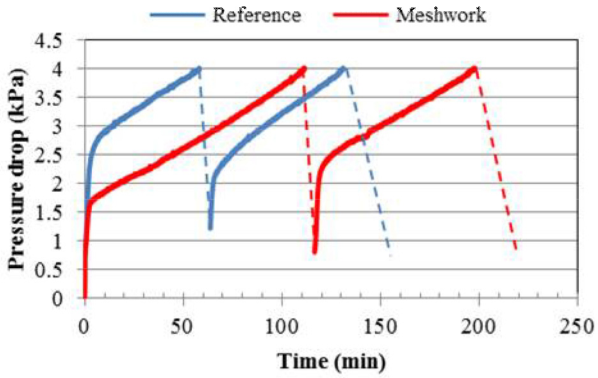

Figure 20. Time for one testing cycle of soot loading and regeneration.

The fuel injection per unit time during soot regeneration was regarded as the same because the engine conditions were fixed for experimental repeatability. The fuel saving effect for a 1000-hour test was then estimated based on the amount of fuel injection and the total elapsed time for one test cycle. Figure 21 shows the estimated normalized fuel consumption. The total fuel consumption of the meshwork catalyst was reduced by 7% compared to the reference sample. This reduction of fuel consumption was derived from the decrease of soot regeneration frequency mainly because of the effect of pressure drop reduction. The pressure drop reduction also contributed to the fuel consumption in soot loading per unit time.

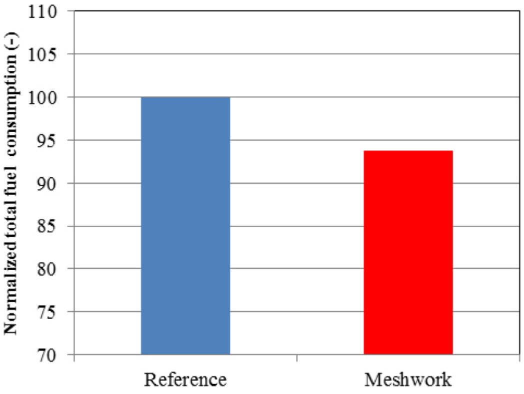

Figure 21. Estimated fuel consumption during 1000 hours of repeated soot regeneration cycles.

SUMMARY AND CONCLUSIONS

In this study, the fundamental performance and fuel economy improvement effects of a unique morphology catalyst, a meshwork DPF, were evaluated using laboratory equipment, an engine bench, and a chassis dynamometer. Experiments were carried out to examine the pressure drop both with and without soot, soot regeneration, and PN filtration, as well as to estimate fuel economy using a conventional catalyzed DPF sample as a reference. The following conclusions were derived from the results of these experiments.

1. The pressure drop experiment results showed that applying the meshwork catalyst onto the inlet channel of the DPF definitely reduces the pressure drop during soot loading by 32% in spite of the slight increase in the initial pressure drop. The pressure drop behavior clearly indicates that the meshwork catalyst minimizes the increase in the pressure drop caused by deep-bed filtration by transferring from deep-bed filtration mode to cake filtration mode more quickly than the conventional catalyst.
2. The results of the PN filtration efficiency evaluation showed a significant improvement of 68% compared to the conventional catalyst. The position and morphology of the meshwork catalyst inhibit soot penetration into the DPF substrate wall effectively even under cold-start.
3. The meshwork DPF catalyst demonstrated remarkable improvement in both the active and passive soot regeneration rates. The active regeneration rate was improved by 35% and the passive regeneration rate was 8 times better. The morphology of the meshwork catalyst improved the soot-catalyst contact and also the proximity of soot-chemical species such as NO_2 and active oxygen.
4. The durability of the meshwork catalyst appeared to be sufficient during practical DPF operation. The structure and function were maintained after thermal shock, even in a worst case scenario like the drop-to-idle condition.
5. The meshwork DPF catalyst was better at suppressing the increase in the pressure drop during soot loading, the regeneration rate, and regeneration intervals. These effects provided great fuel saving during soot loading and repeated regeneration cycles. It was estimated that the fuel saving during 1000 hours of soot loading was approximately by 7%. In particular, it was shown that reducing pressure drop and prolongation of the regeneration interval are an effective means of improving fuel economy.

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DEFINITIONS AND ABBREVIATIONS

CPC - Condensation particle counter
CPSI - Cell per square inch
CVS - Constant volume sampling
DOC - Diesel oxidation catalyst
DPF - Diesel particulate filter
DTI - Drop-to-idle
LNT - Lean NOx trap
NOx - Nitrogen oxides
NO_2 - Nitrogen dioxide
Pd - Palladium
PGM - Platinum Group Metal
PM - Particulate matter
PN - Particulate number
Pt - Platinum
SCR - Selective NOx reduction
SEM - Scanning electron microscope
UF - Under Floor
VPR - Volatile particle remover
WLTC - Worldwide harmonized Light duty driving Test Cycle
