Effects of alumina foam coated with stanum (IV) oxide on the emission of gasoline engine

Shahrin Hisham Amirnordin*, Hamimah Abd. Rahman, Ahmad Sobri Ahmad Hudin, Norwahdah Rahmat, Mas Fawzi Mohd Ali, Suzairin Md Seri, Ahmad Jais Alimin, Mohd Faizal Mohideen Batcha, Wan Saiful-Islam Wan Salim.

Automotive Research Group, Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia (UTHM),
86400 Parit Raja, Batu Pahat, Johor, Malaysia
*Tel: +607-4538482, Fax: +607-4536080, *E-mail: shahrin@uthm.edu.my*

Abstract

Stanum oxide-based materials are known for the catalytic activities on noxious gases. Combination of alumina foam structure and zeolite in filtration, refining and separation of chemical species is seen to increase the capability of such filter. The search for alternative materials are intensifying as the existing catalysts (Platinum Group Metal-PGM) used in honeycomb structure found in typical catalytic converters are prohibitively expensive. This paper reports the effects of stanum (IV) oxide coating on alumina foam as pollutant abatement in gasoline engine. The filter employs polymeric sponge method to obtain porous structure with a composition of 70 vol. % alumina and 30 vol. % of zeolite. The filters are installed on a 1300 cc carburetted engine. Hydrocarbon (HC) and carbon monoxide (CO) emission are measured at several speeds ranging from 1500 rpm to 3500 rpm. The result of the test is compared with a non-filter system. Analysis shows a reduction of both HC and CO emission levels up to 25 % between 1500 rpm to 3500 rpm for alumina foam compared to the non-filter system.

Keywords:

HC, CO, alumina foam, catalytic converter, stanum (IV) oxide.

Introduction

Ceramic foams are brittle materials with closed, fully open, or partially interconnected porosity. It is commercially accepted in many fields with variety of products such as catalysis, filtration, impact absorbing structures, high specific strength materials, biomechanical implants and high efficiency combustion burners [1,2]. In automotive industries, ceramic foams have received particular interest in the development of diesel particulate traps and catalytic converters [3,4].

Commercial catalytic converters employ honeycomb structures, diameter 1~2 mm which results the flow to become laminar. Considerable attention has been given on the structure of the substrate in order to make the flow turbulent [5]. Turbulence is preferred as it improves chemical reaction and thus to enhance turbulence, porous structures have the potential to be employed in design of catalysts. Its open cell structure with interconnected channels offers relatively low-pressure drop, radial mixing and tortuous flow paths to encourage the turbulence [6].

In catalytic converters, Platinum Group Metals (PGM) currently represents state-of-the-art in emission technology. Due to its high cost and low availability, the search for alternative catalysts has received attention from researchers. Previous work has established good activity of tin oxide-based materials against carbon monoxide (CO). Recent data of chromium / stanum (IV) oxide and copper / chromium / stanum (IV) oxide also demonstrated three-way activity comparable to PGM especially against CO and hydrocarbon (HC) [7].

This paper presents the effects of alumina foam coated with stanum (IV) oxide to treat emission from combustion engines, particularly CO and HC gases. Performance and emission testing has been conducted on three configurations of the exhaust system installed with alumina foam, channel alumina foam and non-filter. It is shown that the emission has been reduced up to 25 % for both CO and HC measurement. Further analysis indicates the advantage of channelled alumina foam which is able to minimize the power loss from the engine up to 3.7 %. This is achieved with the presence of channels in the alumina foam structure without affecting the emission capability of the alumina foam.

Methodology

Preparation of Alumina Foam

Alumina foam is prepared using a polymeric sponge method with 90% of alumina and natural zeolite (clinoptilolite) as the main mixture for slurry preparation. Ovalbumin and 10 % of water are added respectively as the carrier and binder for the ceramic slurry. The slurry is stirred until a uniform mixture is obtained. Additional binder is also added into the slurry composition. The next step is the impregnation of polyurethane sponge with the ceramic slurry. The sponge is compressed to remove air and then immersed into the slurry and allowed to expand. This process is repeated to achieve the required ceramic loading. Excess slurry is needed to be removed from the sponge. Then the sponge is dried in a microwave oven before the sintering process commences at 1350°C.

Coating of stanum (IV) oxide

Dip-coating process generally involved 3 stages; immersion, dwell time and withdrawal. In the beginning, the coating mixture is prepared where stanum (IV) oxide is dissolved in distilled water inside a dipping tank. This solution is allowed to settle from 2 to 3 hours before being used for the next process.

The alumina foam is immersed in the solution at constant speed and remains fully immersed about 24 hours. Then it is gradually withdrawn before the drying process in the oven for 24 hours. At this stage, a layer is expected to have been formed on the surface structure of the foam. X-Ray diffraction (XRD) analysis is performed to investigate the presence of stanum (IV) oxide on the alumina foam surface.

Additional process on the channelled alumina foam is required to obtain the channels. Holes with 1 mm of diameter and 10 mm distance from adjacent holes are added. The channelled alumina foam is also coated with stanum (IV) oxide. Similar with alumina foam, ten pieces of the samples are assembled into the casing before the installation into the vehicle exhaust system. Figure 1 shows the comparison between alumina foam and channelled alumina foam (finished product).

Figure 1: Alumina foam (left) and channelled alumina foam (right)

Performance and Emission Testing

The testing is conducted using a chassis dynamometer on a 1300 cc, 4-cylinder, 4-stroke water cooled gasoline engine (model 4G13). Gas emission analyzer is used to measure the emission from the engine as shown in Figure 2. Three exhaust systems are tested as depicted in Figure 3. The first configuration consists of alumina foam coated with stanum (IV) oxide installed in a stainless steel casing. The volume used is identical with the engine capacity of 1300 cc. In the second configuration, channelled alumina foam is used in the system while no filter is used in the third configuration (non-filter system).

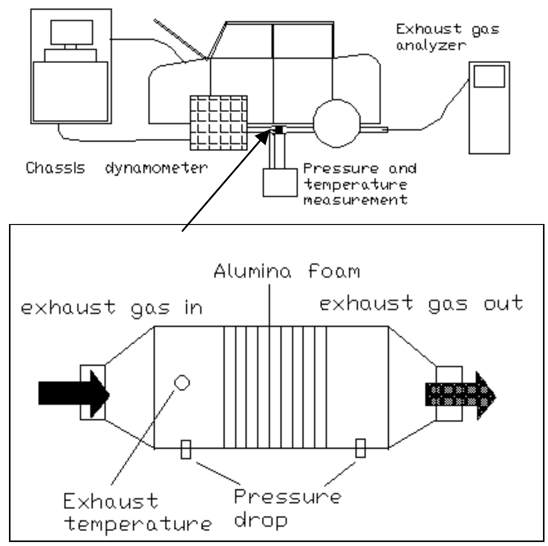
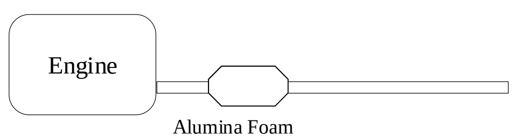
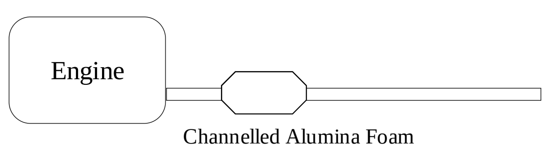


Figure 2: Schematic layout of the performance and emission testing layout (top); pressure and temperature measurement of alumina foam (bottom)



Configuration 1: Alumina foam in the exhaust system



Configuration 2: Channelled alumina foam in the exhaust system

Configuration 3: Non-filter exhaust system

Figure 3: Three configurations of the exhaust system in the performance and emission testing

The performance of engine, emission and pressure drop due to the presence of the alumina foam and exhaust temperature are measured using test equipment as shown in Figure 3. The testing is conducted at constant load (maximum load) with 1500 rpm of engine speed (approximately 43 km/h road speed). Parameters of power, torque, CO and HC emission, pressure drop between the alumina foam (except on configuration 3) and exhaust temperature are measured. The speed is progressively increased by 500 rpm (2000, 2500, 3000 and 3500 rpm) which is equivalent to road speed of 58, 72, 87 and 101 km/h respectively. This testing procedure is applied for all three configurations of exhaust system.

Results and Discussion

<u>XRD Analysis</u>

Figure 4 depicts the XRD analysis from the fresh samples of coated alumina foam showing the presence of stanum (IV) oxide in the alumina powder. High peaks of elements for aluminium oxide and stanum (IV) oxide in Figure 4 suggests the effectiveness of dip coating process in embedding stanum (IV) oxide particles onto the surface of alumina foam.

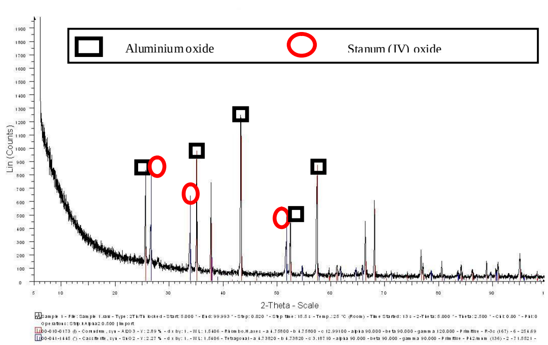


Figure 4: XRD analysis of alumina foam coated with stanum (IV) oxide

<u>Performance Test</u>

Performance of the engine in terms of power for all configurations is displayed in Figure 5 and 6. Power loss from the engine using alumina foam is higher (3.3 to 9.4 % - average is 6 %) compared to channelled alumina foam (1 to 6.2 % - average is 2.7 %). The results depict the potential of channelled alumina foam in filtration activities while minimizing power loss of the engine.

Similar trend is seen for torque measurement. In Figure 7 and 8, comparison of torque indicates channelled alumina foam is closer to standard exhaust system as the deviation ranging from 1.6 to 6.9 % (3.7 % average). Alumina foam gives lower reading as the deviation ranges from 5.7 to 10.9 % (8 % average). Both results of power and torque produced are consistent as channelled alumina foam manages to reduce power loss only 2.7 to 3.7 % compared to non-filter system. The result is encouraging as the use of alumina foam might affect engine performance from 6 to 8 %. Further analysis reveals the reason of this difference.

Pressure drop due to the presence of alumina and channelled alumina foam is shown in Figure 9 and 10. Major constraint in introducing alumina foam in the exhaust systems is that the high pressure drop across the length of the catalyst could reduce engine performance. The result of 32 % average pressure drop reduction from the alumina foam exhibits the effectiveness of introducing channels to the existing alumina foam. The result is consistent with the higher engine performance for channelled alumina foam as compared to alumina foam in Figure 5.

Figure 11 shows the comparison of exhaust temperature measured during the testing of all configurations. The overall result indicates channelled alumina foam achieves the highest exhaust temperature, followed by alumina foam and non-filter system.

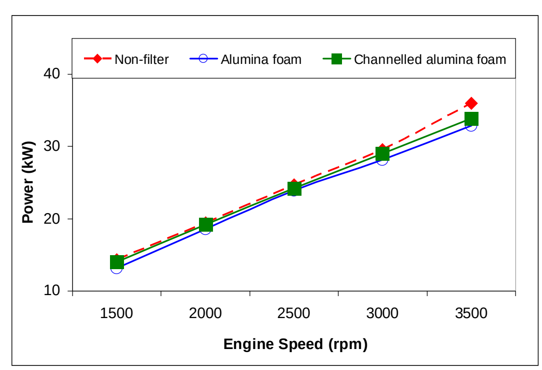


Figure 5: Comparison of engine performance (power) for three configurations

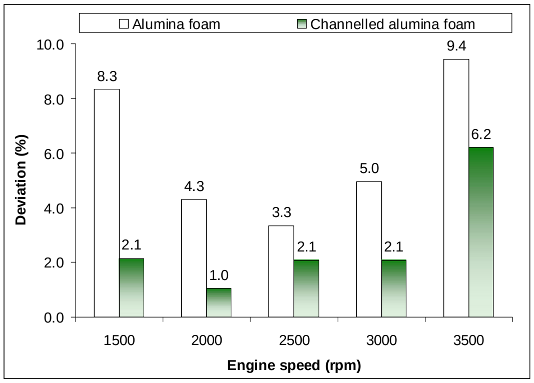


Figure 6: Difference in engine performance (power) for alumina foam and channelled alumina foam from the non-filter system

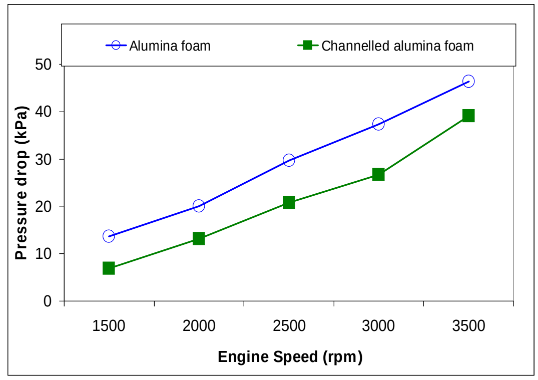


Figure 9: Comparison of pressure drop between alumina foam and channelled alumina foam

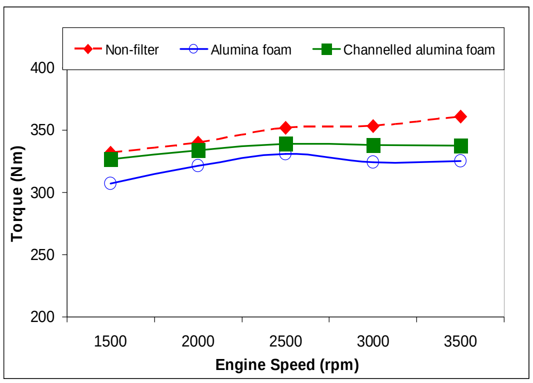


Figure 7: Comparison of engine performance (torque) for three configurations

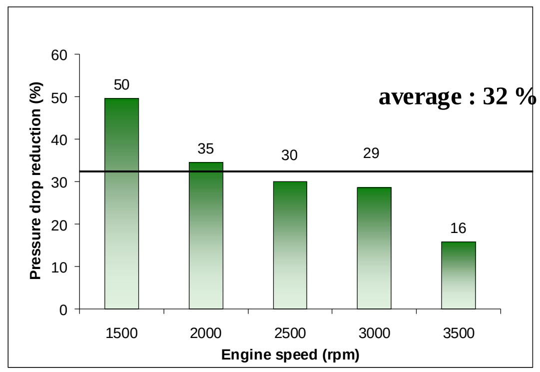


Figure 10: Difference in pressure drop between alumina foam and channelled alumina foam

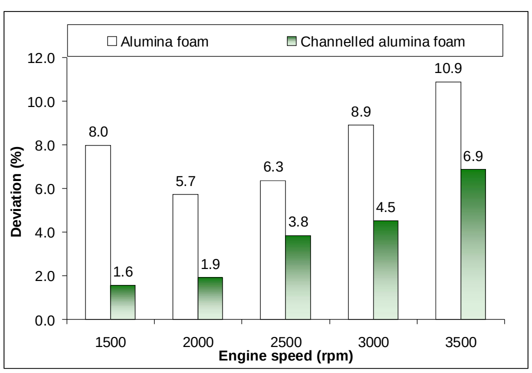


Figure 8: Difference in engine performance (torque) for alumina foam and channelled alumina foam from the non-filter system

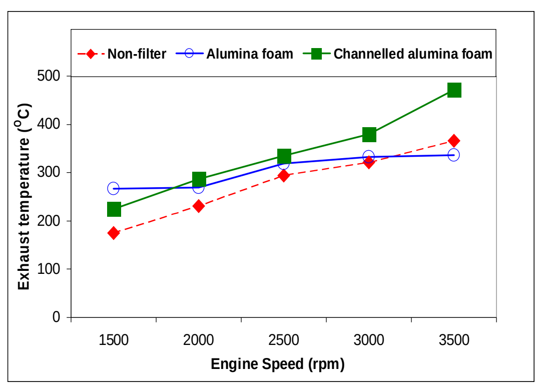


Figure 11: Comparison of exhaust temperature for three configurations

Emission Test

Figure 12 and 13 represent the normalized form of CO and HC emission. The results are plotted as normalized emission by dividing emission concentration of the tested configuration to the concentration emitted in the non-filter system (if the value is larger than 1.0, then the emission is higher than the emission from non-filter system and vice versa).

Effectiveness of alumina foam and channel alumina foam is measured compared to the non-filter system. Both filters display typical trend in emission reduction from 1500 to 3500 rpm of engine speed. No significant effects of CO and HC emission due to structural modification of alumina foam. As a result, channelled alumina foam coated with stanum (IV) oxide is practical to be adopted in the exhaust system.

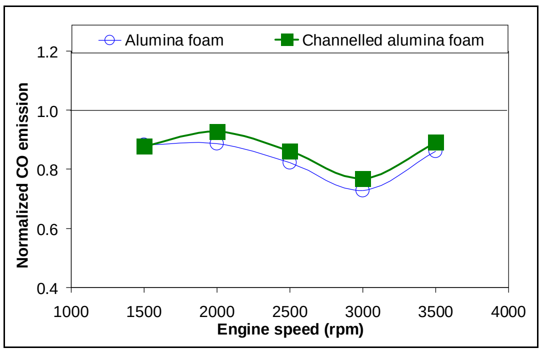


Figure 12: Normalized CO emission of both configurations

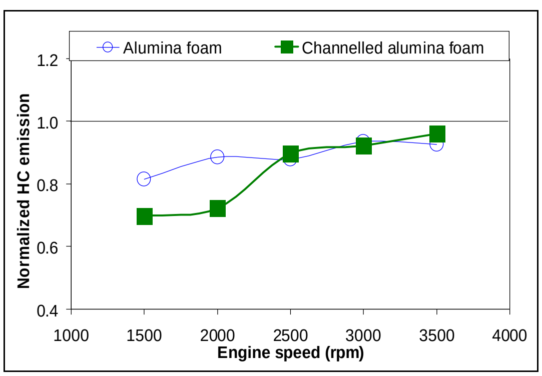


Figure 13: Normalized HC emission of both configurations

Conclusion

The results of performance test here demonstrate only minimal loss of power for alumina foam compared to non-filter system. However, power loss from the engine can be reduced down to 3.7 % by introducing channels to the alumina foam. This is attributed to the average of 32 % pressure drop reduction. CO and HC emission is also seen to improve with the application of alumina foam coated with stanum (IV) oxide. It is also found that addition of channels in alumina foam does not largely influence the capability in emission filtration of the system.

Acknowledgement

The authors would like to thank the Ministry of Higher Education, Malaysia for supporting this research under the Fundamental Research Grant Scheme (FRGS) Vot. 0360.

References

[1] S. Dhara and P. Bhagarva, A Simple Direct Casting Route to Ceramic Foams, Journal of the American Ceramic Society, 2003, Vol. 86, pp. 1645-1650.

[2] S. Sharafat, N. Ghoniem, M. Sawan, A. Ying and B. Williams, Breeder foam : An Innovative Solid Breeder Material For Fusion Application, Journal of American Ceramic Society, 2006, Vol.81, pp. 455-460.

[3] Patent No.: US 6,077,600, Ceramic Catalytic Converter.

[4] Patent No.: US 6,040,266, Foam Catalyst Support for Exhaust Purification.

[5] Hirose, S., Yamamoto, Y., Miyairi, Y., Makino, M., Nakasuji, Y. and Miwa, S., Application of converter efficiency simulation tool for substrate design, Society of Automotive Engineers, (2004-01-1487).

[6] Patcas, F.C., Garrido, G.I. and Czarnetzki, B.K., CO oxidation over structured carriers, Chemical Engineeering Science 62, 2007, pp. 3984-3990.

[7] Wan Azelee Wan Abu Bakar, Nor Aziah Buang and P.G. Harrison, The Characterisation of Chromium (VI)-Promoted Tin (IV) Oxide Catalysts. Buletin Kimia, 1999, 14 (1&2), 1-15.