

Study on In-Cylinder Thermal Barrier Coatings and Evaluation/Analysis Techniques for Reducing Cooling Losses

- (Third Report) Evaluation of Thermal Properties of Thermal Barrier Coatings II -

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Improving the thermal efficiency of internal combustion engines is one of the key challenges in realizing a carbon-neutral society. In particular, the cooling loss through combustion chamber walls represents a major energy loss in internal combustion engines, creating a need for its reduction. The "wall-temperature-swing" thermal insulation method has recently attracted attention as a solution to this issue. This novel thermal insulation technology involves applying a coating with low thermal conductivity and low volumetric heat capacity to the piston crown; by allowing the coating's surface temperature to fluctuate significantly in sync with combustion gas temperature changes during the combustion process, the temperature difference between the gas and the wall is reduced, thereby suppressing heat flux into the wall.

In this study, the Hybrid Aerosol Deposition (HAD) method, developed by the National Institute of Advanced Industrial Science and Technology (AIST), was employed to fabricate thermal barrier coatings for more effective implementation of the wall-temperature-swing concept. The HAD method enables the formation of coatings ranging from dense to porous structures with high adhesion at relatively low temperatures and allows their application to complex three-dimensional geometries. In the previous study, we successfully fabricated a thermal insulation coating with a porosity exceeding 50 % by combining an oblique deposition technique with mesoporous γ -alumina as the coating material, achieving a thermal conductivity of $0.24 \text{ W m}^{-1} \text{ K}^{-1}$ and a thermal effusivity of $0.52 \text{ kJ m}^{-2} \text{ s}^{-1/2} \text{ K}^{-1}$.

The performance of the thermal barrier coatings was evaluated in terms of thermal conductivity and thermal effusivity. These properties were calculated from thermal diffusivity, specific heat capacity, and density. Thermal diffusivity was measured using laser flash and xenon flash methods, and the data were analyzed using a two-layer model consisting of a titanium substrate and a coating layer. Specific heat capacity was determined by differential scanning calorimetry (DSC) using the raw powders employed for coating fabrication. Density was evaluated from bulk density measurements.

To clarify the effects of surface smoothness and open-pore structures on thermal insulation performance, the thermal diffusivity of alumina coatings with a sealing layer was measured. Although the inclusion of a sealing layer resulted in a slight reduction in the difference in thermal diffusivity, this indicates that the sealing layer did not significantly impact the insulation performance.

Additionally, a silica-containing composite coating based on mesoporous γ -alumina was developed as a candidate material for enhancing thermal insulation performance, and its thermal properties were evaluated. As shown in Figure 1, measurements of the silica-containing composite coating samples using the laser flash method confirmed a distinct thermal insulation effect. The coating achieved a high porosity of 65–67 %, as well as a low thermal conductivity of $0.2 \text{ W m}^{-1} \text{ K}^{-1}$ and a low thermal effusivity of $0.45 \text{ kJ m}^{-2} \text{ s}^{-1/2} \text{ K}^{-1}$.

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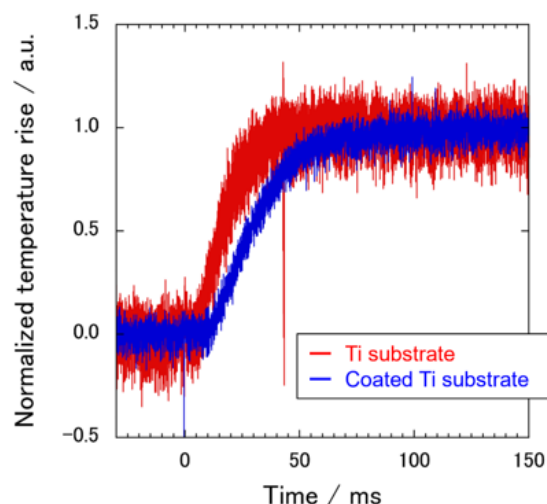


Fig. 1 Example of measurement curves using the laser flash method