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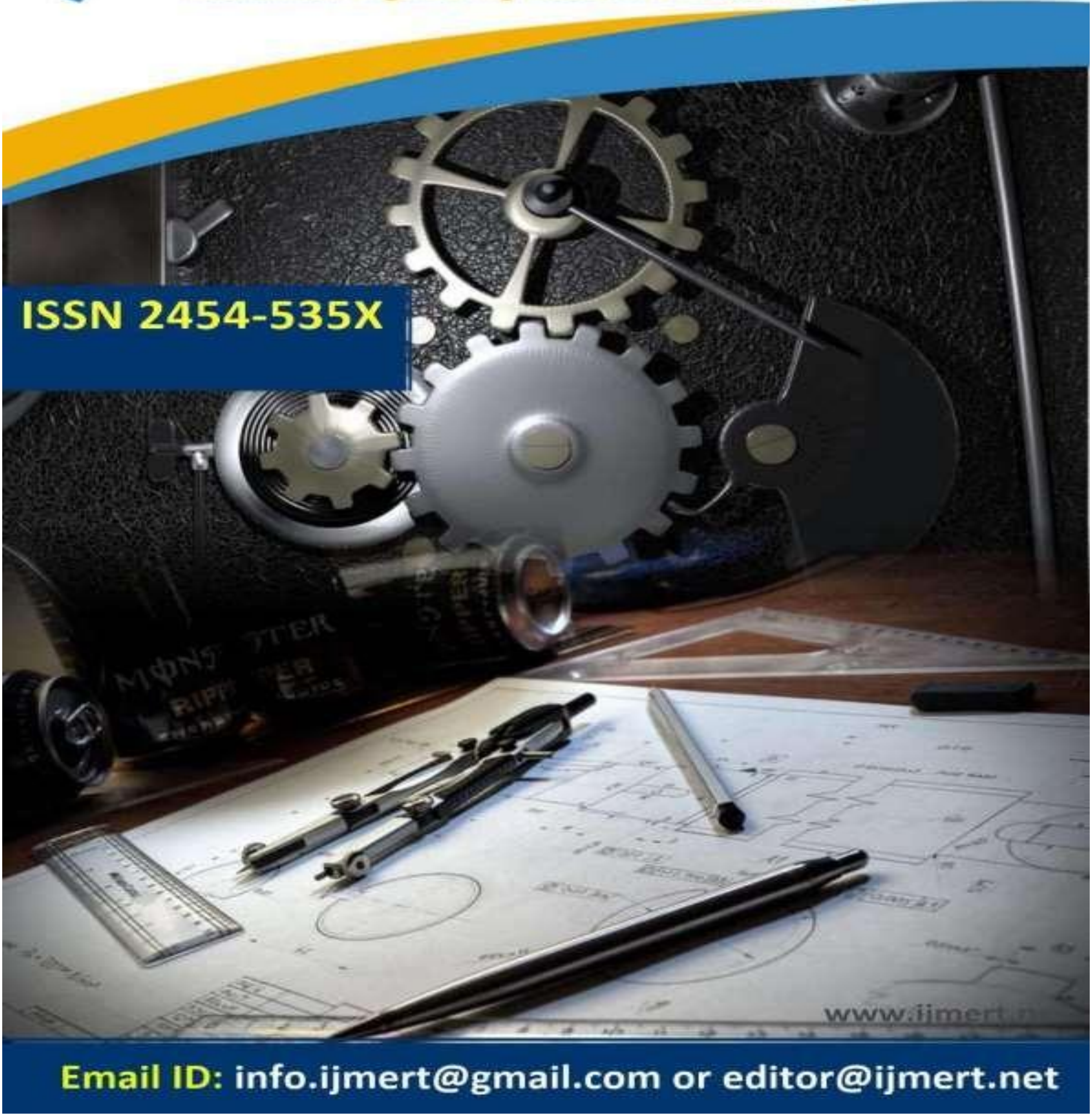

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Preparation and Characterization of Silica-Fiber Aeroger CompositeHeat Insulations

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ABSTRACT:

The purpose of this study is to determine the best method for stacking silica-fiber mats and silica-aerogel core layer to create an excellent sandwich heat insulation. It is believed that a thermal expansion mat for vehicle catalytic converters will be its usual use. This study looks at two alternative preparation methods: one employs a wet method to fabricate the silica-aerogel core layer, while the other uses a dry method where silica short fibers are pre-cured alongside the silica-aerogel core layer. The composite heat insulation can be hot-molded to create rigid structures, including curved surfaces, because silica fiber has the ability to produce a condensation reaction that forms Q4 silica structures when heated above 300°C. This material is ideal for use as a thermal expansion mat in catalytic converters. The manner in which

INTRODUCTION

High performance heat insulations are urgently needed to enhance heat control functions for various technological fields. One of such demands can be seen in a heat insulation mat used between a 3-way catalytic converter and its housing enclosure equipped in exhaust lines of automotive applications. The expansion mat surrounding the catalytic converter should have a good thermal insulation to enhance purification of exhaust gas, because the conversion efficiency of catalytic converter is considerably reduced when its temperature is lowered below 300°C [1-2].

Our previous study proposed a high performance heat insulation including silica aerogel as its main insulation component; as illustrated in Figure 1 [3-4], the composite heat insulation comprises a sandwich structure in which the silica-aerogel core layer is inserted between silica-fiber mats (Belcotex®, Belchem Inc). The core layer also includes SiC and calcium silicate to prevent heat radiation and to provide stability of the whole heat insulation, respectively. The composite heat insulation can be prepared using a doctor blade technique as described later; however, the preparation process must be carefully controlled to obtain uniform distribution of constituent materials. The purpose of this study is to develop appropriate preparation processes for making stable composite heat insulations and to characterize their heat insulation performances.

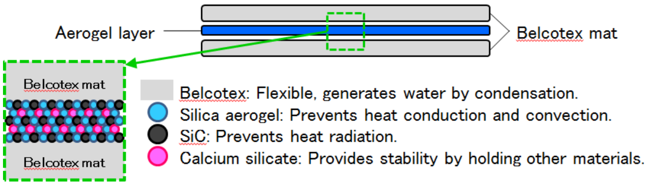

Figure 1. Basic structure of the composite heat insulation.

METHODS

Materials used

Figure 2 shows a silica-fiber mat (Belcotex®) which was used as outer layers of the composite heat insulation. This product hasa flexible texture including three dimensional stitches along the thickness. The fiber has a characteristic to generate condensation reaction forming Q4 silica structures when heated above 300°C and to withstand thermal environment up to 1000°C [5-7].

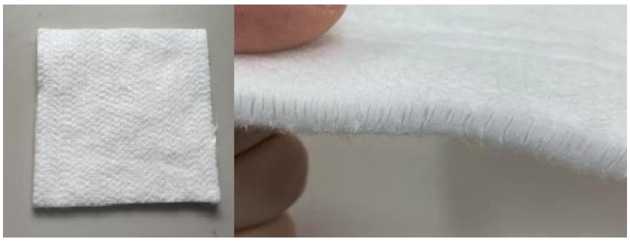

Figure 2. Silica-fiber mat (Belcotex®) used in the composite heat insulation.

The core layer of the composite heat insulation includes silica-aerogels that prevent heat conduction and convection as equivalent as vacuum insulations. SiC and calcium silicate were also added to the core layer to compensate the prevention of heat radiation and mechanical stability of the whole heat insulation. Surfactant water solution and inorganic binders were also added to makeslurry with an appropriate composition when preparing the composite heat insulation by a wet fabrication process described below.

Wet fabrication process of composite heat insulation

The sandwich structure of the composite heat insulation was prepared using a doctor blade technique as illustrated in Figure 3.Silica-aerogel slurry was applied on the silica-fiber mat (150×300×6mm) with a uniform thickness, then the mat was folded halfto have aerogel slurry as the mid-layer. The thickness of aerogel layer was varied to 3, 4, and 5mm to examine the contributionto the heat insulation performance. The composite was subsequently pressed at 10kN to squeeze water, and dried in an oven at70°C for 24h, at 90°C for 1h, and at 130°C for 1h.

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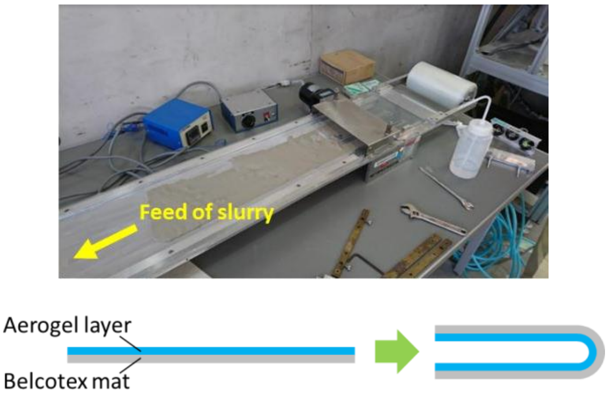

Figure 3. Application of aerogel slurry onto the silica-fiber mat using a doctor blade technique.

An alternative wet preparation process using a simple squeezer tool was also examined to improve qualities of composite heatinsulations in this study. As shown in Figure 4, aerogel slurry was poured onto the silica-fiber mat and immediately spread witha uniform thickness by sliding the squeezer. This quick process may avoid separation of constituents in aerogel slurry by reducingoperation time to make composite heat insulations.

Figure 4. Application of aerogel slurry to the silica-fiber mat using a squeezer technique.

Dry fabrication process of composite heat insulation

In order to improve mechanical stability of the composite heat insulation, a dry fabrication process was also examined. As illustrated in Figure 5, Belcotex$^{®}$ short fibers (BSF, L=5mm) were used to trap silica-aerogels without binders. BSFs and silica-aerogels were pressed together between two Belcotex$^{®}$ mats applying a load of 10kN and heating to 350°C. During the hot-press,

BSFs cause condensation reactions converting their Q3 silica structure into Q4 structure while adhering the outer mats and silica- aerogels to cure rigid composite structure. SiC particles were also dispersed or deposited as a layer to the mid-layer to preventheat radiation through the composite.

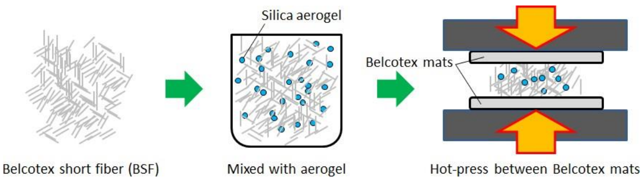

Figure 5. Dry hot-press molding of the composite heat insulation using Belcotex$^{®}$ short fibers.

Measurement of thermal conductivity

Figure 6 illustrates the experimental setup for evaluating thermal conductivity of the composite heat insulation. The test samplewas placed onto the heater plate and heated from 200°C to 700°C at a heating rate of 0.17°C/min. Heat flux and temperature gradient along the thickness of the test sample were measured by a heat flux meter and thermocouples to apply Fourier’s law forcalculating the thermal conductivity.

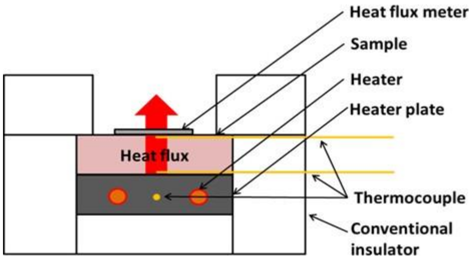

Figure 6. Experimental setup for evaluation of thermal conductivity of the composite heat insulation.

RESULTS AND DISCUSSIONS

Thermal conductivity of composite heat insulation fabricated by wet process

Figure 7 and 8 show appearances and thermal conductivities of composite heat insulations with different aerogel core-layer thicknesses, respectively. Better heat insulation performances were obtained by increasing the aerogel core-layer for the entiretemperature range.

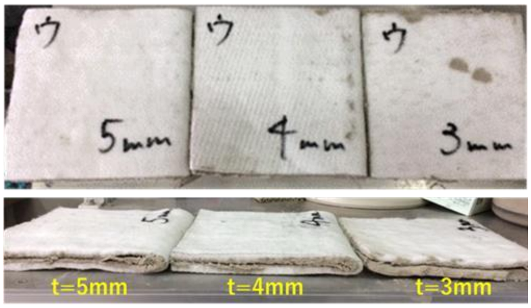

Figure 7. Appearances of composite heat insulations with different aerogel core-layer thicknesses.

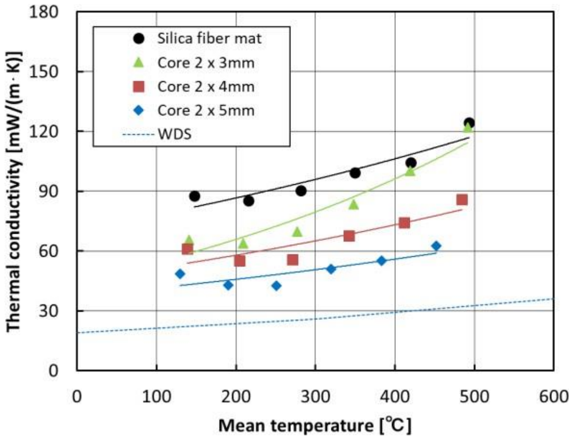

Figure 8. Thermal conductivities of composite heat insulations with different aerogel core-layer thicknesses.

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However, as shown in Figure 9, all of the samples had been damaged showing evident cracks on the heated surfaces of silica-fiber mats due to thermal shrinkage.

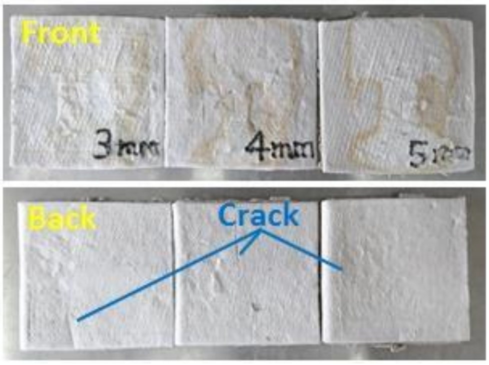

Figure 9. Thermal damages of composite heat insulations after thermal conductivity tests.

Thermal shrinkage of silica-fiber mats can be avoided by subjecting silica-fiber mats to heat treatment at 800°C for 1h beforepreparing composite heat insulations. Figure 10 demonstrates that the heat treatment for silica-fiber mat was effective to preventcracks.

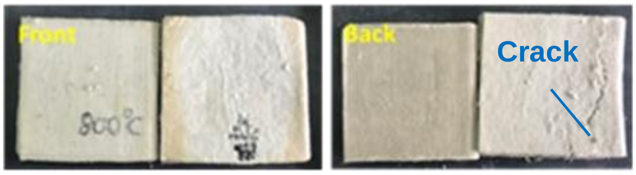

Figure 10. Effect of heat treatment for silica-fiber mats to prevent thermal shrinkage; heat treated sample (left) and non-heattreated sample (right).

Figure 11 shows thermal conductivities of composite heat insulations with 5mm aerogel core-layer thickness; the blue dotted line shows samples made by the doctor blade, whereas the red solid line shows samples made by the squeezer. It is clear that reductionof operation time for applying aerogel slurry contributed to improve reliabilities of composite heat insulations.

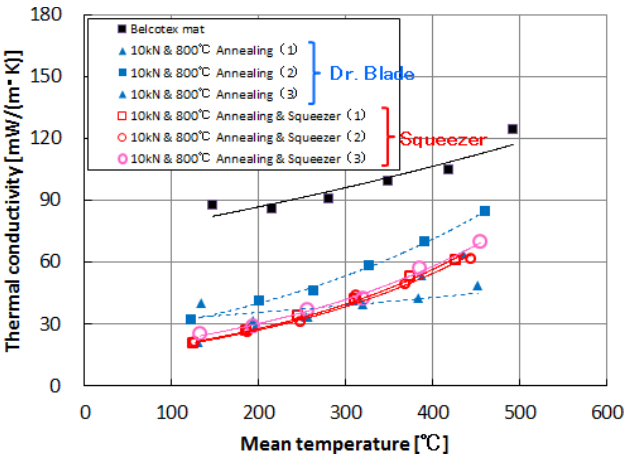

Figure 11. Comparison of thermal conductivity deviations between different wet preparation processes.

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It is also important to consider the role of SiC particles. SiCs were used to prevent heat radiation from the heat source; however, evenly dispersed SiCs may form heat conduction paths across the thickness of the composite heat insulation. Therefore, as depicted in Figure 12, the wet preparation process was modified to make aerogel core-layers have more SiC contents near theheated surface.

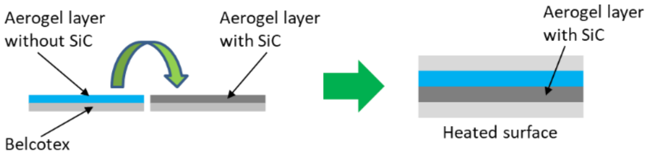

Figure 12. Modification of wet fabrication process to have a graded SiC composition in the core-layer.

Figure 13 shows thermal conductivities of the composite heat insulation including the graded SiC composition in the core layer.The heat insulation performance significantly improved by concentrating SiC particles in the core layer near the heated surface.

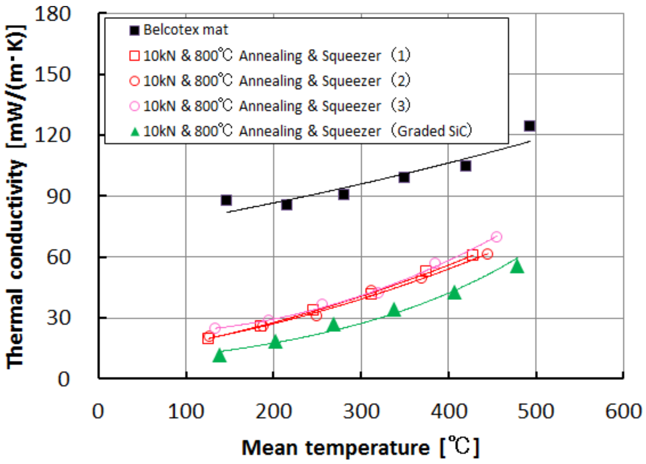

Figure 13. Thermal conductivities of the composite heat insulation with a graded SiC composition in the core-layer.

Thermal conductivity of composite heat insulation fabricated by dry process

Figure 14 shows scanning electron micrographs of the core layer of the composite heat insulation fabricated by the dry processapplying a load of 10kN and heating to 350°C. Silica aerogels have been trapped and adhered to BSFs providing the rigid composite structure.

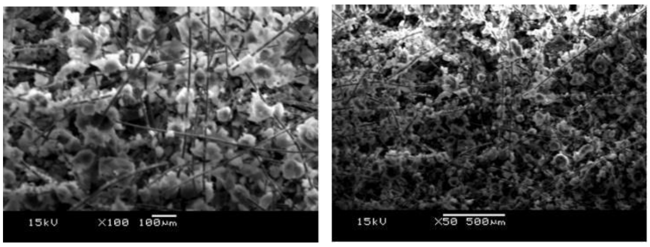

Figure 14. SEM images of the core-layer of the composite heat insulation fabricated by the dry process.

Figure 15 shows appearances of the composite heat insulation after the thermal conductivity test. The composite sample remained intact without any cracks on the silica-fiber mats while keeping its stiffness owing to the rigid adherence between BSFs and silicaaerogels.

Figure 15. Appearances of composite heat insulations made by the dry process after the thermal conductivity test.

Figure 16 compares thermal conductivities of composite samples fabricated by the dry process with different SiC compositions.With no SiC in the core layer, the thermal conductivity at the higher temperature range considerably increased due to heat radiation from the heat source. The influence of heat radiation was relieved by dispersing SiCs in the core layer. The depositionof SiC layer near the heated surface was most effective to prevent both of thermal conduction and heat radiation throughout theentire temperature range.

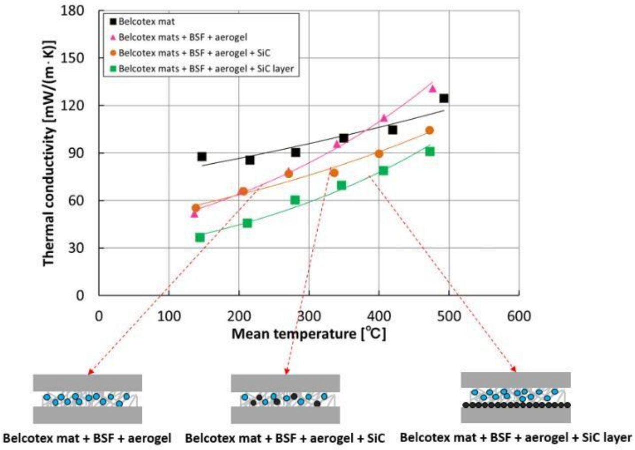

Figure 16. Comparison of thermal conductivities of composite heat insulations fabricated by the dry process with different SiCcompositions.

Press molding of composite heat insulation

Molding flexibility of the composite heat insulation was examined assuming the technical goal to produce expansion mats surrounding 3-way catalytic converters for automotive applications. Figure 17 illustrates a scheme to make curved composites in a trichotomy step to obtain a circumferential heat insulation for a ceramic monolith. This scheme should be applicable to both ofthe wet and dry fabrication processes for the composite heat insulation.

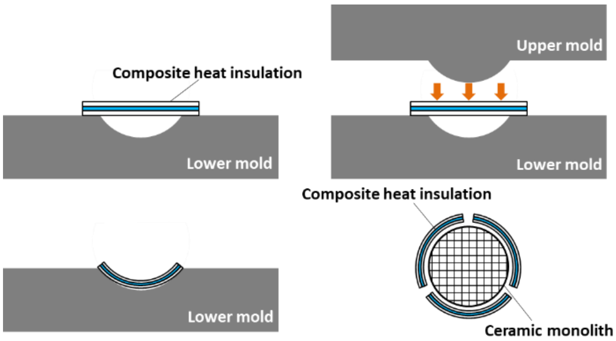

Figure 17. A scheme of press molding for making a circumferential heat insulation for a ceramic monolith.

Figure 18 shows trial results of press molding of curved composite heat insulations. Both products maintained their curved shapes; especially, the dry product had a good stability which will be required for automotive applications.

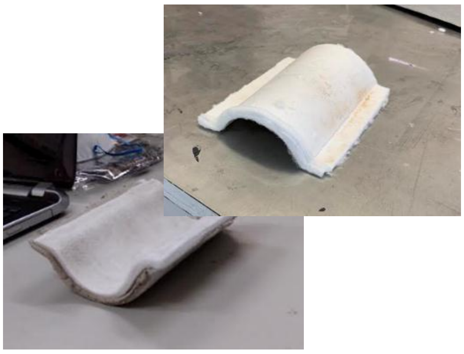

Figure 18. Trial results of press molding of composites made by the wet process (left) and the dry process (right).

CONCLUSIONS

Wet and dry preparation processes of composite heat insulations using silica-fiber mats and silica-aerogels were examined. Characterizations revealed that SiC particles should be included in the aerogel core-layer and near the heated surface to preventheat radiation. Composites fabricated by the wet process had superior heat insulation performances, whereas the dry processproducts showed good mechanical stabilities due to adhesion between silica short fibers and silica aerogels. The composite heatinsulations also had flexibilities to produce circumferential heat insulations for 3-way catalytic converters.

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