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Specific Heat Measurement of High Temperature Thermal Insulations by Drop Calorimeter Method

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By applying the drop calorimeter method, a specific heat measuring apparatus that can be used in the temperature range from 100 to 1000°C has been developed. It is generally difficult to measure the specific heat of thermal insulation, because the insulation material is porous, and has low thermal conductivity and small heat capacity. In the present apparatus, the specific heat of thermal insulation is simply measured by dropping a heated specimen into water. The specific heat of the specimen obtained by the apparatus is the "mean" specific heat between the initial specimen temperature before dropping and the equilibrium water temperature after dropping. This apparatus was used to measure the mean specific heat of standard specimen SRM 720 Synthetic Sapphire (α-Al_2O_3) whose reference values are certified by the National Institute of Standards and Technology (NIST). The measured values agreed well with the reference values within an error of $\pm 10\%$. The specific heats of SiC refractory material, rock wool, alumina silica fiber, alumina silica board, calcium silicate, and SiO_2 glass measured with this apparatus are also presented.

KEY WORDS: drop calorimeter; fibrous insulation; porous specimen; specific heat.

1. INTRODUCTION

Recently, with an increase in the working temperature of furnaces in the semiconductor, computer, and space industries, thermal insulations which can be applied at higher temperature have been developed. In consort with

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this development, the thermal conductivity, which is an important performance index of thermal insulation, is required to be measured under more severe conditions. As a trial to meet the requirement, Ohmura [1], one of the authors, has developed a cyclic heat method type of thermal diffusivity measurement apparatus which can be used in the temperature range from 100 to 1300°C. However, when it comes to determining the thermal conductivity of the specimen from the measured thermal diffusivity, a reliable specific heat value is required. In terms of specific heat measurement of thermal insulations, it is generally difficult because the insulation material is highly porous, and has low thermal conductivity and small heat capacity. Furthermore, the higher the temperature, the more difficult is the measurement. In addition, there are few references on the specific heat of thermal insulation. So, by applying a drop calorimeter method [2], we have designed a mean specific heat measuring apparatus which can be used in the temperature range from 100 to 1000°C. In this paper, we first confirmed the accuracy of the apparatus using a standard material from the National Institute of Standards and Technology (NIST), and then measured the mean specific heats of SiC refractory material, rock wool, alumina silica fiber, alumina silica board, calcium silicate, and SiO_2 glass.

2. MEAN SPECIFIC HEAT AND TRUE SPECIFIC HEAT

The mean specific heat of a material c_s in the temperature range from T_{s2} to T_{s1} ($> T_{s2}$) is given by the following arithmetic mean type of equation [3, 4],

$$c_s = \frac{h_{s1} - h_{s2}}{T_{s1} - T_{s2}} \tag{1}$$

Here, h_{s1} and h_{s2} are the specific enthalpies at T_{s1} and T_{s2}. On the other hand, the true specific heat of the material c_t at the temperature T_{s1} is given by the following differential type of equation [3, 4],

$$c_t = \frac{d}{dT}(h - h_r)\bigg|_{T = T_{s1}} \tag{2}$$

Here, the specific heat h is a function of T, and h_r is the specific heat at an arbitrary reference temperature T_r.

In this study, the specific enthalpies of thermal insulations h_{s1} and h_{s2} at the temperatures T_{s1} and T_{s2} were measured with a drop calorimeter apparatus developed by the present authors, and the mean specific heats were evaluated by using Eq. (1).

3. MEASURING TECHNIQUES AND APPARATUS

The mean specific heat c_s is evaluated by measuring the temperature rise of water, which has been first kept at room temperature, and then reaches a higher equilibrium temperature after the heated specimen is dropped into it. In the evaluation of the mean specific heat c_s, the following two points are taken into consideration.

(1) Since the initial specimen temperature is higher than 100°C, water in the vicinity of the specimen evaporates vigorously, and this leads to heat loss accompanied with vapor released from the measuring system.

(2) The temperature rise of water after dropping a specimen is typically 2 to 15°C, which results in heat loss from water to the internal wall of the water tank (see Fig. 3).

From the above discussion, the relation among the total quantity of heat given up by the high temperature specimen Q_s, the amount of heats obtained by the water and the internal wall of the water tank Q_w and Q_c, and the amount of heat lost from water caused by evaporation are given by

$$Q_s = Q_w + Q_c + m_v r \tag{3}$$

$$Q_s = m_s c_s (T_{s1} - T_{s2}) \qquad [= m_s (h_{s1} - h_{s2})] \tag{4}$$

$$Q_w = (m_{w1} - m_v)\, c_w (T_{w2} - T_{w1}) \tag{5}$$

$$Q_c = m_c c_c (T_{c2} - T_{c1}) \tag{6}$$

Here, c is the mean specific heat, r is the latent heat of evaporation, m is the mass, and T is the temperature. The subscripts c, s, v, w, 1, and 2 represent the internal wall of water tank, the specimen, evaporation, water, before dropping, and after dropping, respectively. Since the measuring system is put in thermal equilibrium conditions before and after dropping the specimen, the following relations are assumed:

$$T_{c1} = T_{w1}, \qquad T_{c2} = T_{s2} = T_{w2} \tag{7a,b}$$

From Eqs. (3) to (7), the mean specific heat c_s in the temperature range from T_{s2} to T_{s1} is given by the following equation,

$$c_s = \frac{\{(m_{w1} - m_v)\, c_w + m_c c_c\}}{m_s} \frac{(T_{w2} - T_{w1})}{(T_{s1} - T_{w2})} + \frac{m_v}{m_s} \frac{r}{(T_{s1} - T_{w2})} \tag{8}$$

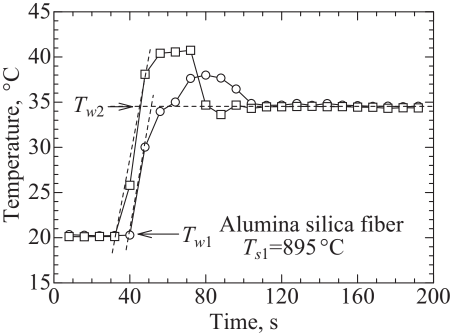
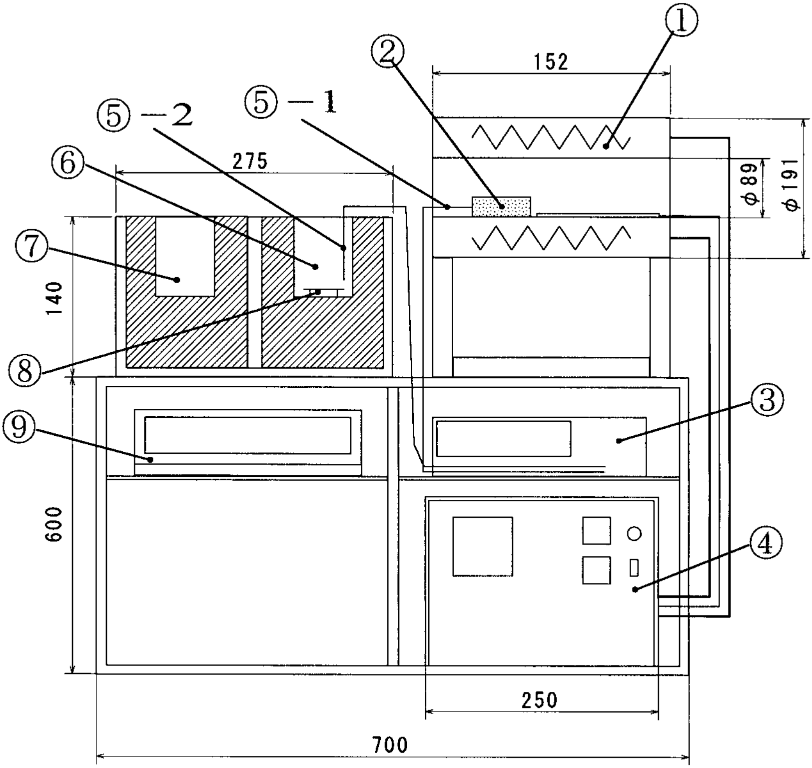


Fig. 1. Example of mean specific heat measurement. T_{w1} and T_{w2} are the water temperatures before and after dropping the specimen.

Figure 1 shows an example of the temperature change of water with time before and after dropping an alumina silica fiber. In this example, the masses of the water and specimen are 47.4 and 3.3 g, respectively. The initial temperatures of the specimen and water are 895 and 20°C, respectively. From the figure, it is seen that the water temperatures measured by two thermocouples (both K-type; 0.3 mm in diameter), one of which is fixed at about 10 mm from the bottom of the water tank and the other is used for both measuring the temperature and mixing the water, rise right after dropping the specimen and then soon settle at some equilibrium temperature. Here, T_{w1} and T_{w2} represent the average water temperatures before and after dropping the specimen, respectively. In Fig. 1, overshoots of water temperatures are observed. This is because the thermocouples come in touch with the high temperature specimen in the water tank.

Figure 2 shows a schematic of the mean specific heat measuring apparatus [1]. As briefly mentioned above, the two thermocouples ⑤-1 are used for measuring the water temperature in the tank ⑥.

The cylindrical heater ① 152 mm long with an ID and OD of 89 and 191 mm can increase the specimen temperature up to 1000°C, and can be inclined down to 20 degrees to the horizontal plane for dropping the specimen easily. The dimensions of the specimen ② are about 20 mm in length, 20 mm in width, and 20 mm in thickness. By weighing the change in water mass by spontaneous evaporation from the water tank ⑦ during the mean specific heat measurement, the amount of vapor released from the water tank ⑥ by vigorous evaporation induced by the high temperature specimen was estimated. Thus, the estimated amount of the vapor was taken into account when evaluating the mean specific heat with Eq. (8). The water tanks ⑥ and ⑦ are ordinary disposable cups made of paper.



① Cylindrical heater
② Specimen
③ Digital multimeter
④ Temperature controller
⑤−1 Thermocouple
⑤−2 Thermocouple
⑥ Measuring water tank
⑦ Monitoring water tank
⑧ Support plate
⑨ Personal computer

Fig. 2. Schematic of mean specific heat measuring apparatus. Dimensions in mm.

The support plate ⑧, which is also made of the same paper as the tanks, is put on the bottom of the measuring water tank ⑥ to prevent heat loss through the tank bottom.

Figure 3 shows a schematic of the measuring water tank ⑥. The tank is composed of two paper cups laminated with each other. This structure enables the water tank to have a thin thermal insulation air layer between the cups. The water tanks ⑥ and ⑦ are surrounded by calcium silicate insulation. The K-type thermocouples of 0.3 mm in diameter are attached on the internal and external walls of the water tank to measure the

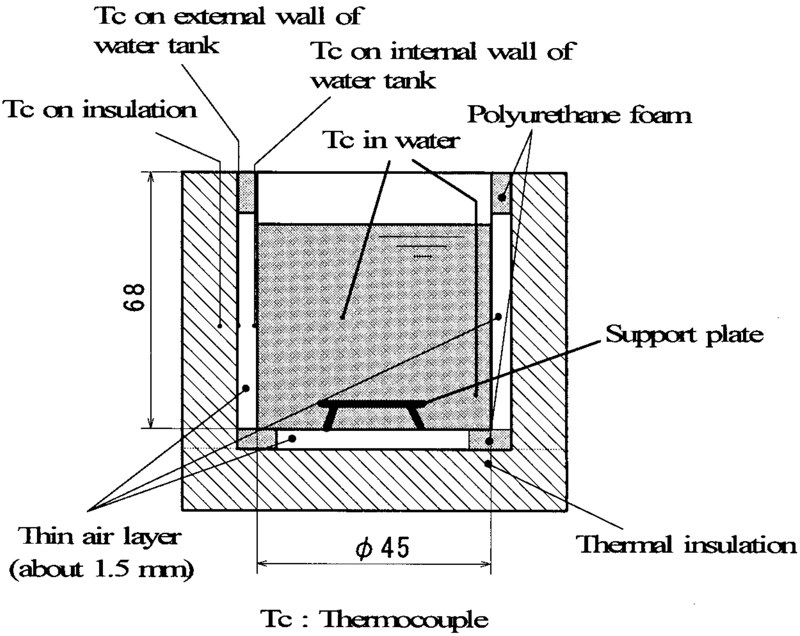


Fig. 3. Schematic of water tank for mean specific heat measurement. Dimensions in mm.

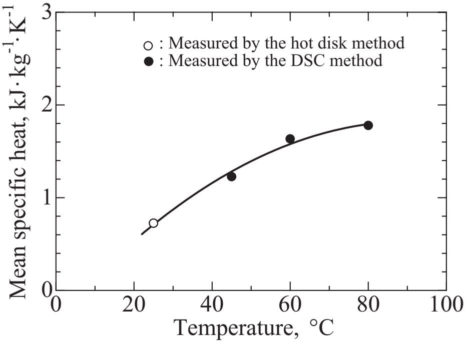


Fig. 4. Mean specific heat of paper used for water tank and support plate: (○) measured by the hot disk method; (●) measured by the DSC method; (——) least squares fit of the measured results.

temperature rise of the water tank after dropping a high temperature specimen.

Throughout the present measurements, a value of $4.18\,\mathrm{kJ \cdot kg^{-1} \cdot K^{-1}}$ [5] was adopted as the specific heat of water c_w. The mean specific heat of the paper used for the water tank and the support plate was measured with the hot disk and DSC methods. Figure 4 shows the measured specific heat of the paper. Broadly, the specific heats shown in Fig. 4 can be considered to be the true specific heat. This is because the present specific heats of the paper were evaluated under small temperature differences. For example, when measured at 60°C with the DSC method, the temperature range in the measurement is from 55 to 65°C. In the same manner, the specific heat was obtained using the hot disk method in the temperature range from 20 to 25°C. Anyhow, based on those measured results, we adopted $1.17\,\mathrm{kJ \cdot kg^{-1} \cdot K^{-1}}$ as the mean specific heat of the water tanks and the support plate.

4. MEASUREMENT ERROR

4.1. Heat Loss When Dropping a Specimen

During the process of moving a specimen from the cylindrical heater to the measuring water tank, some amount of heat is lost necessarily from the specimen to the ambient air. Then, to determine the amount of heat loss, we measured the temperature change of a specimen with time. A specimen with almost the same dimensions as the specimens in the present measurements was held with a pair of tweezers in air after taking it out from the cylindrical heater. The temperature change of the specimen was measured by a K-type thermocouple of 0.3 mm in diameter which was inserted at the center of the specimen.

Figure 5 shows the measured temperature change with time. The symbols ◇, □, △, and ○ represent the results measured at the initial specimen temperatures of 100, 300, 600, and 1000°C (that is, before taken out from the cylindrical heater), respectively. Here, the dimensionless temperature on the longitudinal axis represents the temperature difference between the specimen center and the ambient air normalized by the difference between the initial specimen temperature and the ambient air temperature. From the figure, even if two seconds are required to move the specimen from the cylindrical heater to the measuring water tank, the temperature drop of the specimen during the process is within 3%. Therefore, the ratio of the quantity of heat lost from the specimen to the ambient air Q_{I} to the

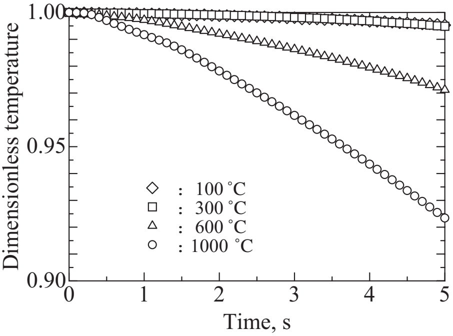


Fig. 5. Transient temperature change of a sample cube in air (Temperature at the center of the cube): ◇, □, △, ○ are the measured values at initial specimen temperatures of 100, 300, 600, 1000°C, respectively.

total quantity of heat held by the specimen at the initial state Q_s is given by

$$\frac{Q_\mathrm{I}}{Q_s} \times 100 \leqslant 3\% \tag{9}$$

However, in the above investigation, only the temperature change at the specimen center is taken into consideration, which may lead to an underestimation of Q_I. Accordingly, we re-estimated Q_I by using a chart on heat loss of a sphere with time on referring to the literature [6], for instance. In the present estimation, the cubic specimen (20 mm × 20 mm × 20 mm) was regarded as a sphere with an equivalent radius of 12.4 mm. The bulk density, the specific heat, and the thermal conductivity of the specimen, and the mean heat transfer coefficient between the specimen and the ambient air were assumed to be 130 $\mathrm{kg \cdot m^{-3}}$, 1000 $\mathrm{J \cdot kg^{-1} \cdot K^{-1}}$, 0.2 $\mathrm{W \cdot m^{-1} \cdot K^{-1}}$, and 15 $\mathrm{W \cdot m^{-2} \cdot K^{-1}}$, respectively. From the chart for the required time of 2 s, the ratio of the heat Q_I lost from the specimen to the ambient air to the total quantity of heat Q_s held by the specimen at the initial state is given by

$$\frac{Q_\mathrm{I}}{Q_s} \times 100 \leqslant 5\% \tag{10}$$

4.2. Heat Loss to Measuring Water Tank and Thermal Insulation

In the evaluation of mean specific heats using Eq. (8), heat loss to the internal wall of the measuring water tank Q_c is considered as explained in

Table I. Temperature Rise in Each Part of Water Tank

	Initial specimen temperature (°C)	100	300	600
Temperature rise (°C)	Water in tank	0.43	2.1	6.0
	Internal wall of water tank	0.34	2.0	6.1
	External wall of water tank	0.24	1.5	3.5
	Thermal insulation	0.18	0.76	2.4

the previous Section 3 (see Eq. (6)). However, heat losses to the external wall of the water tank and the surrounding thermal insulation are not taken into account here. In this section, we show the results on the effects of those heat losses on the accuracy of measurement.

Table I lists the temperature rise in each part of the measuring water tank system after dropping a rock wool specimen with initial temperatures of 100, 300, and 600°C. The temperature rise of water in the tank is almost the same as that of the internal wall of the tank. As for the temperature rises of the external wall of the water tank and the surrounding thermal insulation, relatively high values were observed. Then, to investigate it in more detail, we estimated the amount of heat that could be accumulated in each part of the water tank system after dropping the specimen.

Table II shows an example estimated by using the temperature rise listed in Table I for the specimen mass $m_s = 2.64$ g and the initial temperature $T_{s1} = 600$°C. Here, the mean specific heat of water c_w is referenced to a value in the literature [5]. Concerning the heat accumulated in the thermal insulation, it was estimated by assuming that the heat flowing in from the water tank is accumulated in the surrounding layer of 3 mm thickness, which is about 8% of its mean thickness of 40 mm. From the estimation described above, the ratios of the quantities of heat accumulated in the external wall of the water tank Q_{II} and in the thermal insulation Q_{III} to the

Table II. Accumulated Heat in Each Part of Water Tank

	Mass (g)	Specific heat ($\mathrm{kJ \cdot kg^{-1} \cdot K^{-1}}$)	Temperature rise (°C)	Accumulated heat (J)
Water in tank	46.8	4.18	6.0	1.18×10^3
Internal wall of water tank	4.25	1.17	6.1	30.3
External wall of water tank	4.25	1.17	3.5	17.6
Thermal insulation	4.52	1.02	2.4	11.1

total quantity of heat held by the specimen at the initial state Q_s (in this example, 1.27×10^3 J) are given by

$$\frac{Q_{\mathrm{II}}}{Q_s} \times 100 = \frac{17.6}{1.27 \times 10^3} \times 100 \cong 1.4\% \tag{11}$$

$$\frac{Q_{\mathrm{III}}}{Q_s} \times 100 = \frac{11.1}{1.27 \times 10^3} \times 100 \cong 0.9\% \tag{12}$$

4.3. Error Caused by Assumption of Constant Specific Heats for Water Tank and Water

As shown in Fig. 4, the mean specific heat of the water tank changes with temperature. When the temperature of the water tank changes by ±3°C at a temperature of 40°C for instance, its mean specific heat c_c changes by about $\pm 0.15\ \mathrm{kJ \cdot kg^{-1} \cdot K^{-1}}$. Then, by using the values shown in Table II, the quantity of heat Q_{IV} corresponding to this change in the mean specific heat c_c is estimated at an initial specimen temperature 600°C, for example, the following result is obtained.

$$Q_{\mathrm{IV}} = 4.25 \times 0.15 \times 6.1 = 3.9\ \mathrm{J} \tag{13}$$

Therefore, the ratio of the quantity of heat Q_{IV} corresponding to the change in c_c to the total quantity of heat held by the specimen at the initial state Q_s is given by

$$\frac{Q_{\mathrm{IV}}}{Q_s} \times 100 = \frac{3.9}{1.27 \times 10^3} \times 100 \cong 0.3\% \tag{14}$$

Meanwhile, the specific heat of water is 4.175 to $4.183\ \mathrm{kJ \cdot kg^{-1} \cdot K^{-1}}$ in the temperature range from 20 to 40°C [5]. Therefore, it can be considered that the change in the specific heat of water has virtually no effect on the evaluation of the mean specific heat of specimen.

4.4. Error Accompanying Evaporation of Water

The amount of water that evaporates from the measuring water tank was estimated by subtracting a mass change before and after dropping a specimen in the monitoring water tank from that in the measuring water tank. In the present study, the amount of evaporation is 30 to 50 mg, and a balance which has a minimum scale of 0.1 mg was used for the measurements. As for the latent heat of evaporation, its value is 2454 to

2406 kJ · kg^{-1} in the temperature range from 20 to 40°C [5], and here, the value was assumed to be 2436 kJ · kg^{-1}. Furthermore, the amount of heat dissipated to raise the temperature of water from 20 to 100°C is neglected in Eq. (8). Therefore, the error accompanying the evaporation of water is given by

$$\frac{Q_{\mathrm{V}}}{Q_s}=\frac{\left[\begin{array}{l}2436\times 10^3\times 0.1\times 10^{-6}+(2436-2406)\times 10^3\times 50\times 10^{-6}\\ \quad +50\times 10^{-6}\times 4180\times(100-20)\end{array}\right]}{1.27\times 10^3}\times 100=1.45\% \tag{15}$$

4.5. Total Heat Loss

From Eqs. (10) to (15) shown above, the ratio of the overall heat loss Q_{loss} arising during mean specific heat measurements to Q_s is given by

$$\frac{Q_{\mathrm{loss}}}{Q_s}\times 100=\frac{Q_{\mathrm{I}}+Q_{\mathrm{II}}+Q_{\mathrm{III}}+Q_{\mathrm{IV}}+Q_{\mathrm{V}}}{Q_s}\times 100\cong 9.1\% \tag{16}$$

Therefore, the measurement error in the present system can be estimated to be about 9% at maximum.

5. SPECIFIC HEAT MEASUREMENT OF STANDARD MATERIAL

To confirm the accuracy of measurement for the present apparatus, we measured mean specific heats of the standard material SRM 720 Synthetic Sapphire (α-$\mathrm{Al_2O_3}$), whose reference values are certified by the National Institute of Standards and Technology (NIST) [7].

NIST has proposed the following approximation equation for the specific enthalpy h ($\mathrm{J\cdot mol^{-1}}$) of α-$\mathrm{Al_2O_3}$ in the temperature range from 0 to 900°C (the absolute temperature θ; from 273.15 to 1173.15 K).

$$h-h_{273.15}=d_{-2}\theta^{-2}+d_{-1}\theta^{-1}+d_{ln}\ln\theta+d_0+d_1\theta+d_2\theta^2+d_3\theta^3+d_4\theta^4+d_5\theta^5 \tag{17}$$

Here,

$$\begin{array}{lll} d_{-2}=6.6253\times 10^7, & d_{-1}=-4.54238\times 10^6, & d_{ln}=-5.475599\times 10^4,\\ d_0=2.5819702\times 10^5, & d_1=2.574076\times 10^2, & d_2=-8.57516\times 10^{-2}\\ d_3=4.299063\times 10^{-5}, & d_4=-1.15192\times 10^{-8}, & d_5=1.26351\times 10^{-12}\end{array} \tag{18}$$

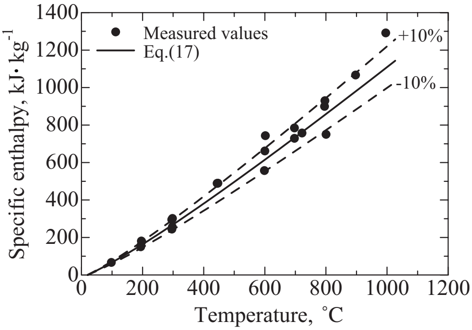


Fig. 6. Specific enthalpy of the standard specimen SRM 720 Synthetic Sapphire (α-Al_2O_3): (●) measured values; (——) Standard values by NIST; (– – –) ±5% deviations from the solid line.

The specific enthalpy h was measured using an Bunsen ice calorimeter, and θ represents the initial specimen temperature.

For the purpose of comparing the specific enthalpies measured by the present apparatus with those calculated by Eq. (17), we first recalculated the specific enthalpy differences $h-h_{293.15}$ using Eq. (17). Here, $h_{293.15}$ is the specific enthalpy at 20°C. The results are shown in Fig. 6. The symbol ● shows the measured specific enthalpies, and these values are plotted against the initial specimen temperature T_{s1}. The solid line represents the specific enthalpy $h-h_{293.15}$ by NIST, and is also plotted against T_{s1}. The two broken lines are ±10% deviations from the solid line. As seen from the figure,

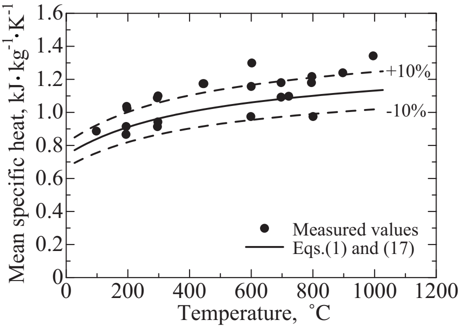


Fig. 7. Mean specific heat of the standard specimen SRM 720 Synthetic Sapphire (α-Al_2O_3): (●) measured values; (——) Standard values by NIST; (– – –) ±5% deviations from the solid line.

Table III. Thermal Insulations Measured in This Study

	Density ρ ($\mathrm{kg \cdot m^{-3}}$)	Measured temperature range T_{s1} (°C)
SiC refractory material	2800	290 to 1000
Rock wool	100	100 to 700
Alumina silica fiber	130	100 to 1000
Alumina silica board	320	200 to 800
Calcium silicate	120	100 to 1000
SiO_2 glass	2465	200 to 600

the measured results agree with the reference solid line within ±10% in the temperature range from 100 to 1000°C.

Similarly, Fig. 7 compares the measured mean specific heats with the reference solid line by NIST. In the figure, the solid line was obtained by substituting Eq. (17) into Eq. (1), that is, by dividing $(h_{s1} - h_{293.15})$ by $(T_{s1} - 20)$. Here, the meanings of the symbol ● and the two broken lines are the same with those in Fig. 6. In this example, too, the measured results agree with the reference solid line within almost ±10% in the temperature range from 100 to 1000°C.

From the results shown above, the present apparatus can be said to have sufficient accuracy to measure the mean specific heats of thermal insulations for practical use.

6. MEASURED MATERIALS

Six kinds of thermal insulations selected in this study are listed in Table III. Here, ρ means bulk density, except for SiO_2 glass. The composition of each thermal insulation [8, 9] is also shown in Table IV.

Table IV. Composition of Each Thermal Insulation (mass%)

	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	SiC
SiC refractory material	–	20	–	–	–	80
Rock wool	40.7	14.9	33.3	5.5	2.6	–
Alumina silica fiber	50	50	–	–	–	–
Alumina silica board	60	40	–	–	–	–
Calcium silicate	43.5	7.1	29.0	0.7	2.9	–
SiO_2 glass	75	15	–	–	–	–

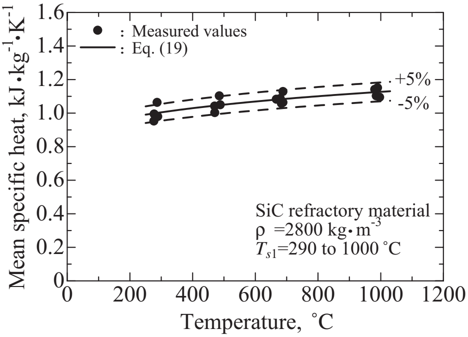


Fig. 8. Mean specific heat of SiC refractory material: (●) measured values; (——) least squares fit of the measured results; (– – –) ±5% deviations from the solid line.

7. RESULTS AND DISCUSSION

The mean specific heats c_s of the SiC refractory material, the rock wool, the alumina silica fiber, the alumina silica board, the calcium silicate, and the SiO_2 glass are shown in Figs. 8–13, respectively. In each figure, the mean specific heat values are plotted against the initial specimen temperature T_{s1}. The symbol ● represents the measured values, and the solid line represents the following logarithmic equation approximated by using least squares.

$$c_s = c_0 + c_1 \ln \theta \tag{19}$$

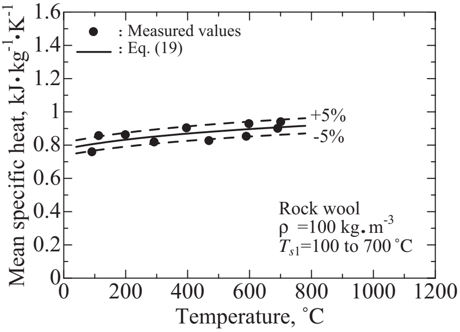


Fig. 9. Mean specific heat of rock wool: (●) measured values; (——) least squares fit of the measured results; (– – –) ±5% deviations from the solid line.

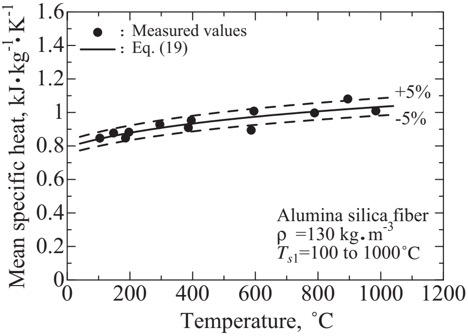


Fig. 10. Mean specific heat of alumina silica fiber: (●) measured values; (——) least squares fit of the measured results; (– – –) ±5% deviations from the solid line.

Here, the coefficients c_0 and c_1 are listed in Table V. Furthermore, the broken lines indicate ±5% deviations from the solid line. From these figures, it can be seen that the mean specific heats of various kinds of materials are distributed within ±5% deviations from Eq. (19).

Although mean specific heats of many kinds of ceramics (for example, Al_2O_3, SiC, SiO_2, etc.) have been measured over a wide range of temperatures, there are few references on mean specific heats of thermal insulations which are made of ceramics. Even if there are some reference values, the method of measurement, initial specimen temperatures, and other important information are rarely specified. Furthermore, in some cases, compounding

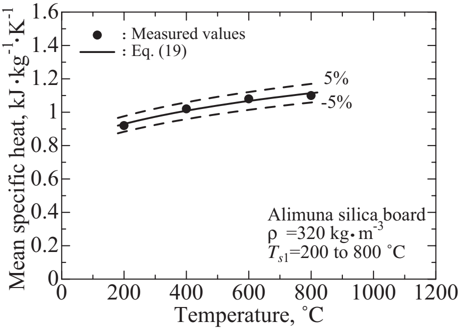


Fig. 11. Mean specific heat of alumina silica board: (●) measured values; (——) least squares fit of the measured results; (– – –) ±5% deviations from the solid line.

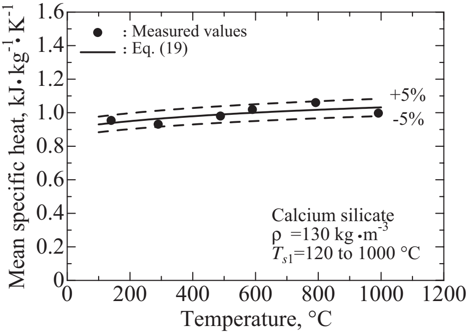


Fig. 12. Mean specific heat of calcium silicate: (●) measured values; (——) least squares fit of the measured results; (– – –) ±5% deviations from the solid line.

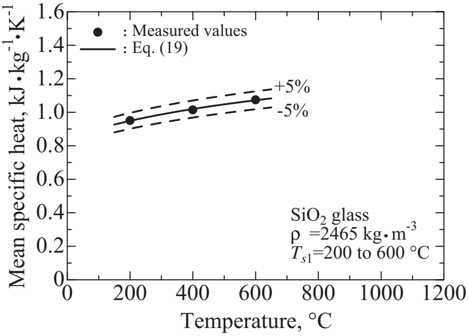


Fig. 13. Mean specific heat of SiO_2 glass: (●) measured values; (——) least squares fit of the measured results; (– – –) ±5% deviations from the solid line.

Table V. Coefficients of Eq. (19) for Various Types of Thermal Insulations

	c_0	c_1
SiC refractory material	3.37×10^{-12}	1.53×10^{-1}
Rock wool	1.91×10^{-1}	1.04×10^{-1}
Alumina silica fiber	-8.75×10^{-2}	1.57×10^{-1}
Alumina silica board	-4.59×10^{-1}	2.25×10^{-1}
Calcium silicate	4.39×10^{-1}	8.29×10^{-2}
SiO_2 glass	-2.86×10^{-1}	2.01×10^{-1}

ratios of materials in thermal insulations, which are commercially available under the same name, differ from one another depending on companies. So, for the present state, it is difficult to compare the measured results with other results. Collecting data on mean and true specific heats of thermal insulations whose conditions of measurements are precise and comparisons with relevant investigations are the subject for a future study.

8. CONCLUSIONS

By applying the drop calorimeter method, we have designed a mean specific heat measuring apparatus that can be used in the temperature range from 100 to 1000°C. Using this apparatus, we first measured mean specific heats of the standard material SRM 720 Synthetic Sapphire (α-Al_2O_3), whose reference values are certified by the National Institute of Standards and Technology (NIST), and confirmed that the measured results agreed with the reference values within $\pm 10\%$ deviations. Next, based on the results, we measured the mean specific heats of SiC refractory material, rock wool, alumina silica fiber, alumina silica board, calcium silicate, and SiO_2 glass. Furthermore, for those thermal insulations, we presented logarithmic equations for the mean specific heat expressed as a function of the initial specimen temperature.

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