Hot Disk®

Application Note

Testing Specific Heat Capacity of Cylindrical, Button, and Pouch Batteries using Hot Cell™ sensors

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This application note presents the development and application of our innovative Hot Cell™ sensors. These have been tailored for testing batteries of all modern types: cylindrical-cell; button-cell; pouch-cell; and prismatic-cell.

Hot Cell™ sensors are used to directly, and very accurately, measure the Specific Heat Capacity (Cp) of samples of any complex structure or geometry. What makes the Hot Cell™ method unique is that the sensors can be scaled up in dimension to accommodate specific heat capacity testing of all geometries, including voluminous samples or components, such as decimeter-long and -wide pouch-cell batteries. This is not possible with other techniques, such as the Differential Scanning Calorimetry (DSC) technique, where only a tiny volume of a sample battery can be tested. The Hot Cell™ method can thus furnish the true Cp-value of a range of complete batteries, including their casing, electrodes, monitoring electronics, etc.

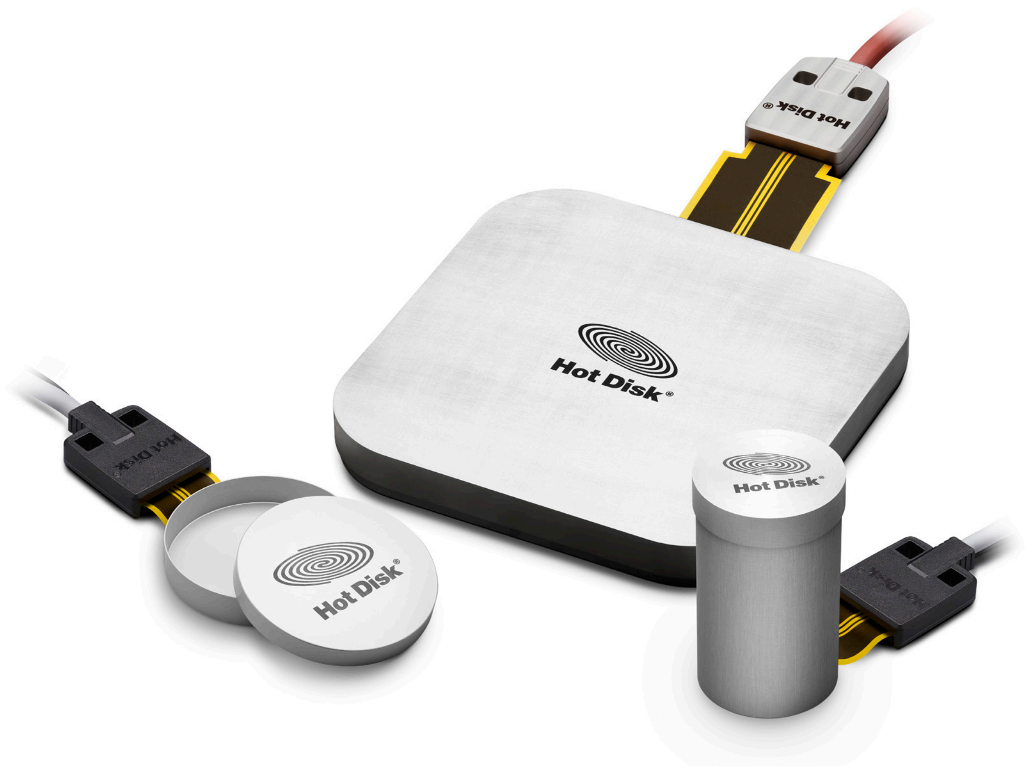

Figure 1. Hot Cell™ sensors for testing a cylindrical battery (left); a button battery (middle); and a pouch battery (right).

In the widespread transition toward gr een energy, rechargeable batteries play a very important role as energy storage components. For example, they are vital for enabling electric vehicles extended mileage. Battery performance, while not overheating, relies heavily on their effective thermal management. This in turn depends not only on their anisotropic thermal conductivity properties, but also on their specific heat capacity properties. For battery manufacturers, precise knowledge of the relevant specific heat capacity is therefore critical.

Here we demonstrate the ease of testing the specific heat capacity of three common types of batteries with the Hot Cell™ method: cylindrical, button, and pouch batteries, using our novel Hot Cell™ sensors dedicated for battery testing. These consist of an aluminum cell with lid, and a TPS-element permanently attached to the cell's bottom. During a measurement, the battery inside the aluminum cell is embedded with an insulating foam, and then heated a few degrees by the attached TPS-element. For this heating to be effective, the size and shape of the aluminum cell needs to be adapted to the battery size and shape in question. For testing of cylindrical, button, and pouch batteries, the cell will come respectively in a tall cylinder shape; as a flat cylinder; and as a flat box with rounded edges. Testing of cylindrical batteries is somewhat more challenging (requiring relative long heating time) as the battery contact area with the aluminum cell is limited. In this case it can be helpful to use some silicone oil to improve the thermal contact. Figure 2. Illustrates a Hot Cell™ sensor for testing cylindrical batteries, embedded in insulating foam.

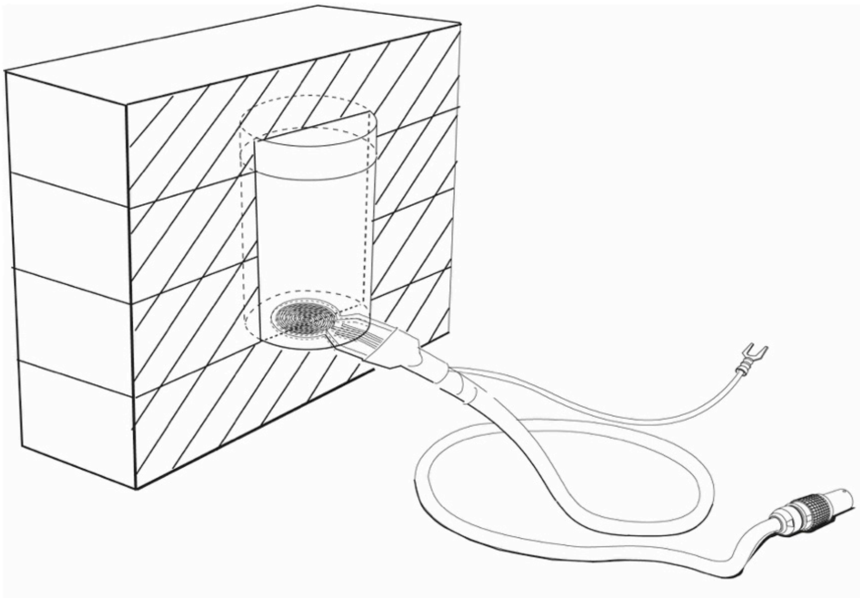

Figure 2. Schematic cross-sectional view of the Hot Cell™ sensor for cylindrical battery testing, illustrating the tall cylindrical aluminum cell with attached TPS-element, and the insulating foam embedding.

A specific heat capacity measurement with our Hot Cell™ sensors requires two transient temperature recordings. The first recording will be made without the sample inside the aluminum cell, while the second recording will include sample inside the aluminum cell. Basically, the first transient is a reference measurement that provides the Cp of the Hot Cell™ sensor considered in isolation, while the second measurement yields the Cp of the combined sample and Hot Cell™ sensor. From these two results the Cp of the sample itself can be extracted with high accuracy. **Figure 3.** shows an example of a transient temperature recording, with and without a cylindrical battery sample inside the relevant aluminum cell.

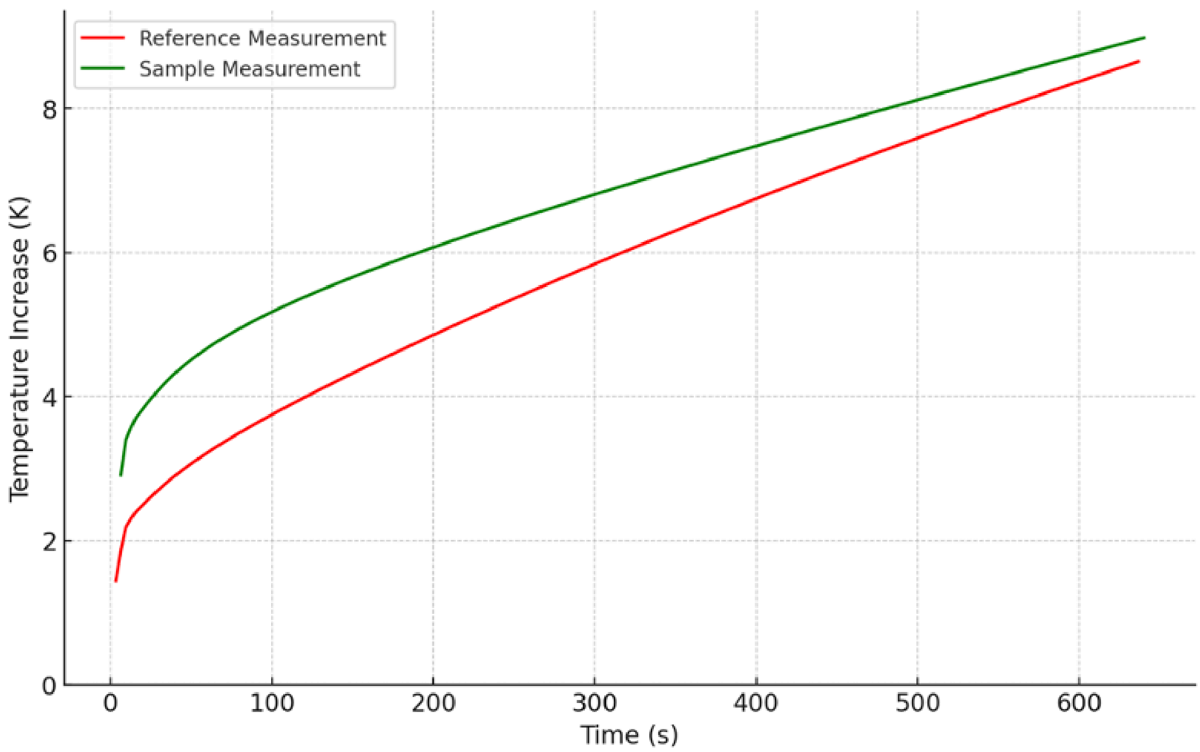

Figure 3. Example of a transient temperature recording using Hot Cell™ sensor model AL-D50-H85, without (red curve) and with (green curve) battery sample 2 (cylindrical-cell Li-ion battery model 21700). The measurement power was 500 mW and 800 mW in the former and latter cases, respectively.

Battery Samples

In this application note we demonstrate direct specific heat capacity (Cp) testing using the Hot Cell™ method[1]. This on six different Lithium battery samples of varying size and type: two of cylindrical-cell type; two of button-cell type; and two of pouch-cell type. **Table 1** lists the details of the six battery samples, as well as the applied Hot Cell™ sensor model for the respective battery samples. (We are not allowed to disclose the battery manufacturers that supplied us with these samples, hence they are anonymized.)

Cylindrical-cell battery	Button-cell battery	Pouch-cell battery
Li-ion battery sample 1 Type: Cylindrical cell Model: 14500 Diameter: 13 mm Length: 51 mm Mass: 21.7 gm Volume: 6.76 cm^3 **Hot Cell sensor** Model: AL-D15-H70	**Lithium battery sample 3** Type: Button cell Model: CR2032 Diameter: 20 mm Thickness: 3.16 mm Mass: 3.06 gm Volume: 0.99 cm^3 **Hot Cell sensor** Model: AL-D20-H5	**Lithium battery sample 5** Type: Pouch cell Width: 60 mm Length: 76 mm Thickness: 4 mm Mass: 43.87 gm Volume: 18.24 cm^3 **Hot Cell sensor** Model: AL-W80-L80-H12
Li-ion battery sample 2 Type: Cylindrical cell Model: 21700 Diameter: 22 mm Length: 75 mm Mass: 70.96 gm Volume: 28.5 cm^3 **Hot Cell sensor** Model: AL-D50-H85	**Lithium battery sample 4** Type: Button cell Model: CR3032 Diameter: 30 mm Thickness: 3.17 mm Mass: 6.86 gm Volume: 2,2 cm^3 **Hot Cell sensor** Model: AL-D70-H12	**Lithium battery sample 6** Type: Pouch cell Width: 201 mm Length: 190 mm Thickness: 8 mm Mass: 873.8 gm Volume: 324.76 cm3 **Hot Cell sensor** Model: AL-W240-L240-H20

Table 1. Lithium battery samples and applied Hot Cell™ sensor models.

Measurement Results

All testing reported here was performed using a Hot Disk® TPS 2500 S instrument. Before testing the Lithium battery samples, we conducted tests on stainless steel verification samples with the Hot Cell™ sensors. Table 2 lists the details of the verification samples, measurement conditions, and Cp results. For reference we also include Cp results from tests using the standard Hot Disk® method[2] and compared the differences. With Hot Disk® sensors the thermal conductivity and thermal diffusivity of a sample are measured simultaneously, and the specific heat capacity of the sample is calculated from these two accrued properties. This indirect method of testing Cp is very accurate for homogeneous isotropic materials but not for anisotropic and/or heterogeneous materials, such as complete batteries, primarily because the testing is limited to a volume of the sample. The results in **table 2** demonstrate that the Cp values obtained by the Hot Cell™ method differ less than 3.7% on average from those obtained by the standard Hot Disk® method on verification samples.

Hot Cell sensor and measurement parameters	Stainless steel verification sample	Measured volumetric Cp using Hot Cell method ($MJ/m^3/K$)	Measured volumetric Cp using Hot Disk method ($MJ/m^3/K$)	Difference (%)
Model: AL-D50-H85 Meas. time: 640 s Meas. Power[1]: 3.0 (1.0) W	Material: AISI 316/316L Diameter: 49.5 mm Thickness: 85 mm	3.83	3.70	3.50
Model: AL-D40-H9 Meas. time: 80 s Meas. Power[1]: 2.9 (0.7) W	Material: AISI 316/316L Diameter: 41 mm Length: 8.3 mm	3.60	3.74	3.70
Model: AL-D70-H12 Meas. time: 160 s Meas. Power[1]: 6.5 (1.1) W	Material: AISI 316/316L Diameter: 60 mm Length: 12.4 mm	3.80	3.71	2.40
Model: AL-W80-L80-H12 Meas. time: 160 s Meas. Power[1]: 5.6 (2.8) W	Material: AISI 316/316L Diameter: 60.0 mm Thickness: 12.4 mm	3.79	3.71	2.10

[1]Measurement power in parenthesis indicates the reference transient recording (i.e. without the battery sample inside the aluminum cell).

Table 2. Testing Cp with Hot Cell™ sensors and Hot Disk® sensors, on verification samples.

Next, the six (fully charged) Lithium battery samples were tested using the Hot Cell™ sensors. **Table 3** lists the measurement conditions and the Cp results in units of J/kg/K, as this unit is more common in the literature for Lithium batteries. Overall, we find that the obtained Cp-values with the Hot Cell™ sensors are trustworthy, well-aligned with available data in the literature.

Lithium battery sample and measurement parameters	Measured specific heat capacity using a Hot Cell sensor (J/kg/K)
Sample 1 (cylindrical cell) Meas. time: 640 s Meas. Power[1]: 0.45 (0.3) W	870
Sample 2 (cylindrical cell) Meas. time: 2560 s Meas. Power[1]: 0.48 (0.3) W	862
Sample 3 (button cell) Meas. time: 80 s Meas. Power[1]: 0.5 (0.25) W	785
Sample 4 (button cell) Meas. time: 80 s Meas. Power[1]: 2.0 (1.8) W	734
Sample 5 (pouch cell) Meas. time: 160 s Meas. Power[1]: 2.8 (2.2) W	820
Sample 6 (pouch cell) Meas. time: 640 s Meas. Power[1]: 6.5 (5.0) W	892

[1]Measurement power in parenthesis indicates the reference transient recording (i.e. without the battery sample inside the aluminum cell).

Table 3. Measurement results of Cp tests on Lithium batteries using Hot Cell™ sensors.

References

1 M. Gustavsson, N. S. Saxena, E. Karawacki and S. E. Gustafsson. "Specific Heat Measurements with the Hot Disk Thermal Constant Analyser", *Thermal Conductivity* 23 (1995)

2 Silas E. Gustafsson, "Transient Plane Source Techniques for Thermal Conductivity and Thermal Diffusivity Measurements of Solid Materials", *Review of Scientific Instruments* 62 (3), pp. 797–804 (1991).

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