Determining the internal pressure in 18650 format lithium ion batteries under thermal abuse

Frank Austin Mier[a], Michael J. Hargather[a], Summer R. Ferreira[b]
(a) Mechanical Engineering Dept., New Mexico Tech, (b) Sandia National Laboratories

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Abstract

Lithium batteries have a well-known tendency to fail violently under abuse conditions which can result in venting of flammable material. Understanding these events can aid in evaluating safety associated with individual battery cells and battery packs when these fluids are vented. The external fluid dynamics of the venting process, including liquid droplets and gases, is directly related to the internal pressure of the battery cell. In this work, battery case strain is measured on cells under thermal abuse which is then used to calculate the internal pressure via hoop and longitudinal stress relations. Strain measurement is a non-invasive approach which will have no bearing on the decomposition within batteries that leads to thermal runaway. Complementary tests are performed to confirm the strain-pressure relationship by pressurizing 18650 cell caps to failure with an inert fluid. A laboratory setup with a heated test chamber was designed and fabricated to remotely subject cells to heating rates up to 6 ˚C/min. Additional measurements include cell temperature and the test chamber pressure, temperature, and heat flux. Variables explored in these tests include cell chemistry, state of charge, and heating rate.

Battery venting under abuse conditions

Most commercial batteries have a vent to relieve pressure as gases are generated under abuse conditions. Shown in Figure 1(a), these events can be highly energetic, and quantitatively describing these events can aid in understanding risks and aid in smart design. Previous work at New Mexico Tech has focused on high-speed schlieren imaging the gas and liquid flows from lithium ion batteries under various abuse conditions as shown in Figure 1(b) while current efforts focus on measuring the pressure which drives these flows [1].

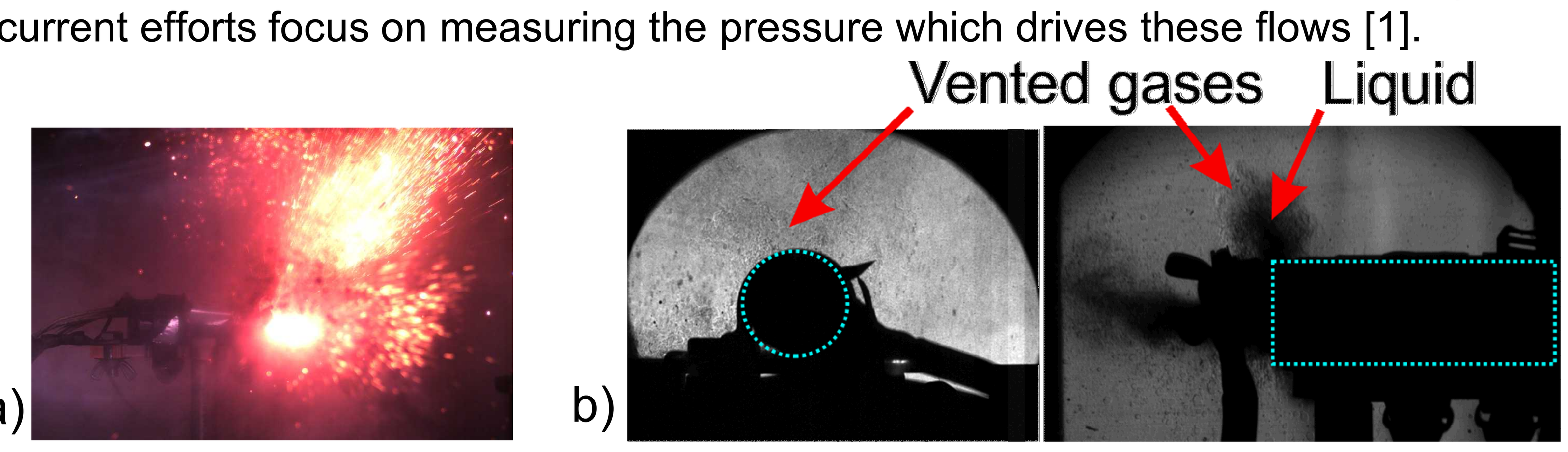


Figure 1: (a) An 18650 cell venting during abuse testing which lead to combustion of expelled material. (b) Schlieren images of a different test from end and side views.

Direct pressurization of battery vent caps

An apparatus has been designed and constructed to accurately measure the burst pressure of battery vents under pressurization with dry air to best describe how venting will occur and to support the battery case strain tests. Typical 18650 construction includes a vent mechanism that is crimped in place as part of the positive terminal of a cell. The vents tested here are removed from actual cells, and the entire vent mechanism remains intact as seen in Figure 2.

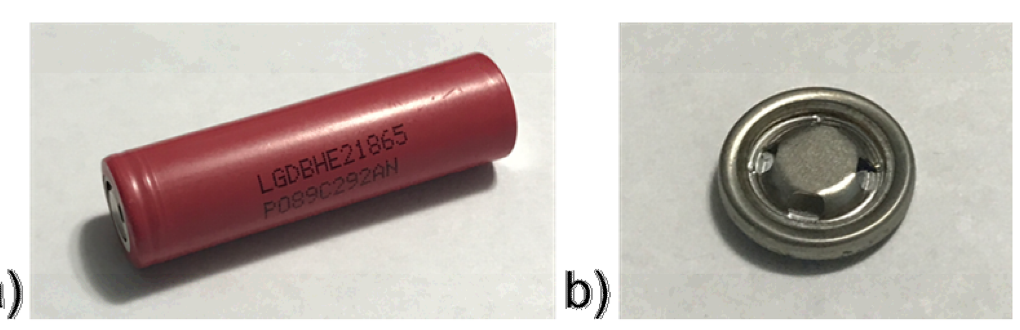


Figure 2: (a) An intact 18650 format battery (LG HE2) and (b) the vent cap after removal.

Shown in Figure 3, major components included in this setup are the battery vent cap holder, accumulator tank, pressure regulator, and compressed air cylinder. Air from the cylinder is used to slowly pressurize the tank, vent cap holder, and thus the battery cap itself to a regulated level. The accumulator tank has a volume of 76 L to reduce stagnation pressure changes once the vent has opened.

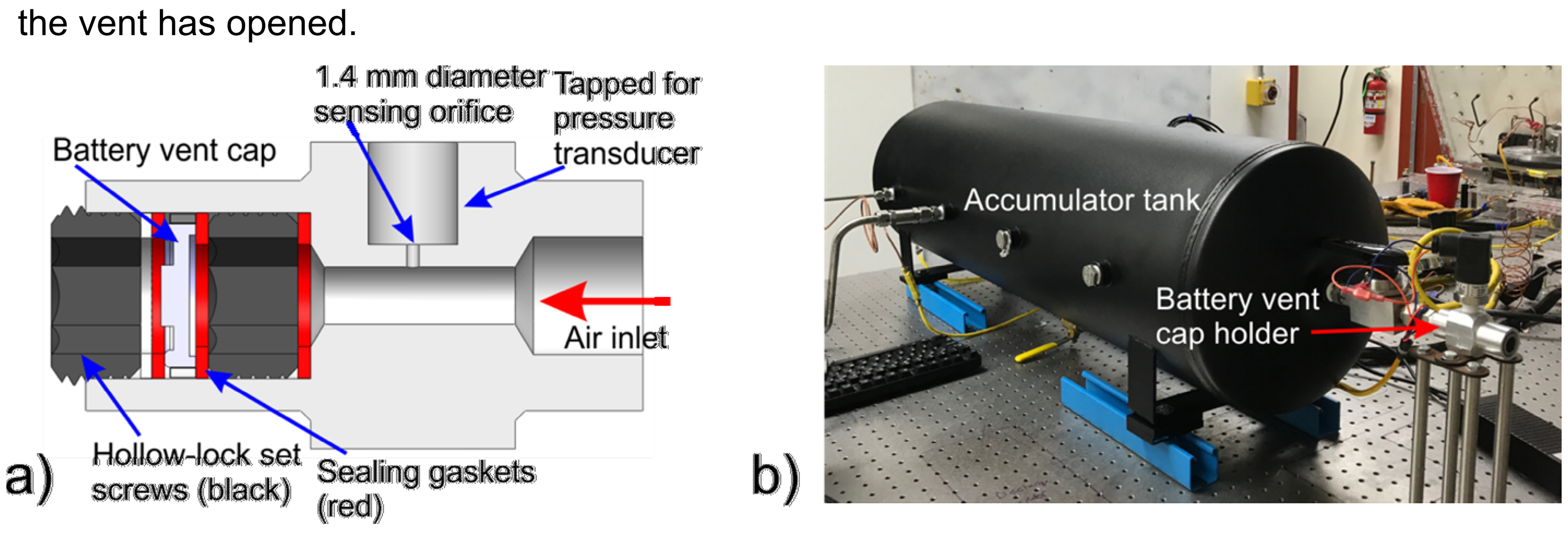
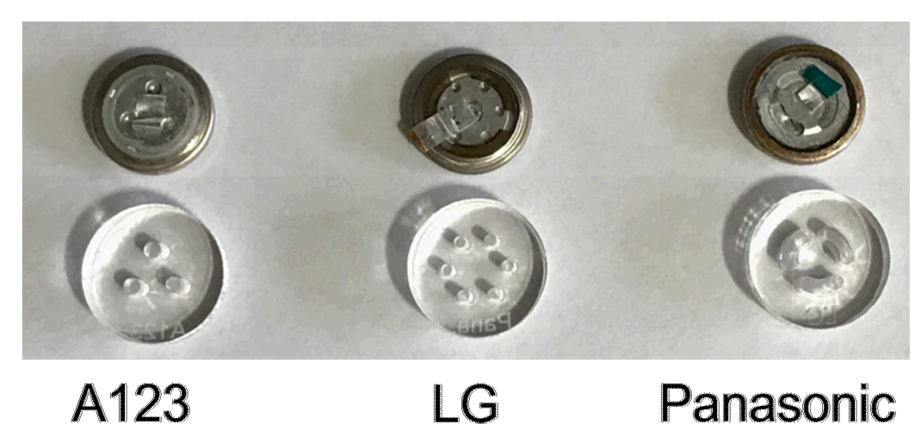


Figure 3: (a) Schematic representation of the battery vent cap holder and (b) the completed test setup installed at New Mexico Tech.

Vent opening area calculation and validation tests

Since the battery vent has the minimum cross-sectional area of the test setup and pressure in the tank is sufficiently high, airflow will choke at the vent cap. Measurement of the stagnation pressure within the tank and static pressure at the known cross-section allows for calculation of the battery vent area. A series of circular test orifices were made in various sizes to validate this measurement. Test orifices were also made with patterned holes to represent the geometries seen on actual vent caps as shown in Figure 4. These orifices are used in lieu of the battery cap during validation tests. Figure 5 shows the accuracy of orifice area calculations.



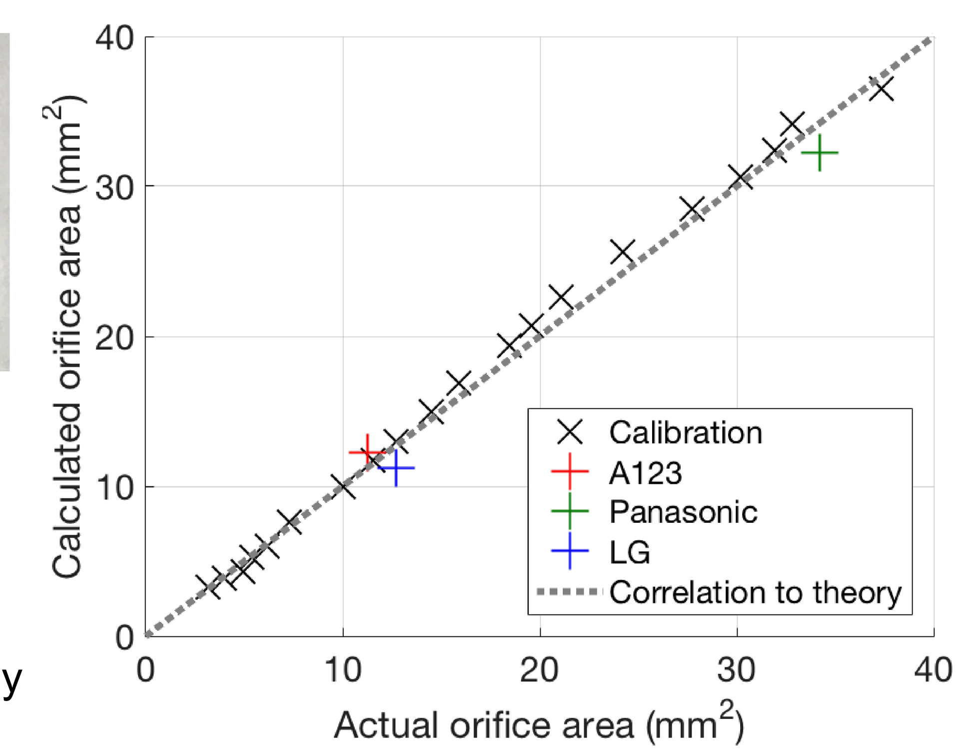


Figure 4: (above) The internal surface of battery vent caps and orifice plates made to mimic the maximum possible opening area.

Figure 5: (right) Results of validation testing by comparing actual and calculated opening areas.

Initial testing with LG HE2 caps

The pressure limit of the accumulator tank was reached without burst of the battery vent caps. However, to provide preliminary results, caps were pressurized directly from a compressed air cylinder with a minimized flow rate. As battery vents remain open after burst, they were able to be tested with the apparatus seen in Figure 3(b). Testing results are shown in Table 1.

Table 1: Initial testing summary

	Burst pressure (kPa)	Opening area (mm^2)
1	1,940.9	7.3
2	1,823.7	7.1
3	1,992.6	6.5

Pressure calculation via battery case strain measurements during abuse testing

Strain gauges are used to perform noninvasive measurement of hoop and longitudinal strain of battery cases under thermal abuse conditions. Strain measurements are the sum of pressure and thermal expansion components. Internal pressure is analytically calculated from geometry, case material properties, and the two strain measurements.

A laboratory test chamber was constructed to perform these strain experiments in a thermally controlled environment as shown in Figure 7. Heating rate is aided by an insulation structure and testing in a helium environment. Measurements include battery temperature, chamber temperature and pressure, and heat flux. Heat rate calibration was performed between 468 W and 1,872 W as shown in Figure 6.

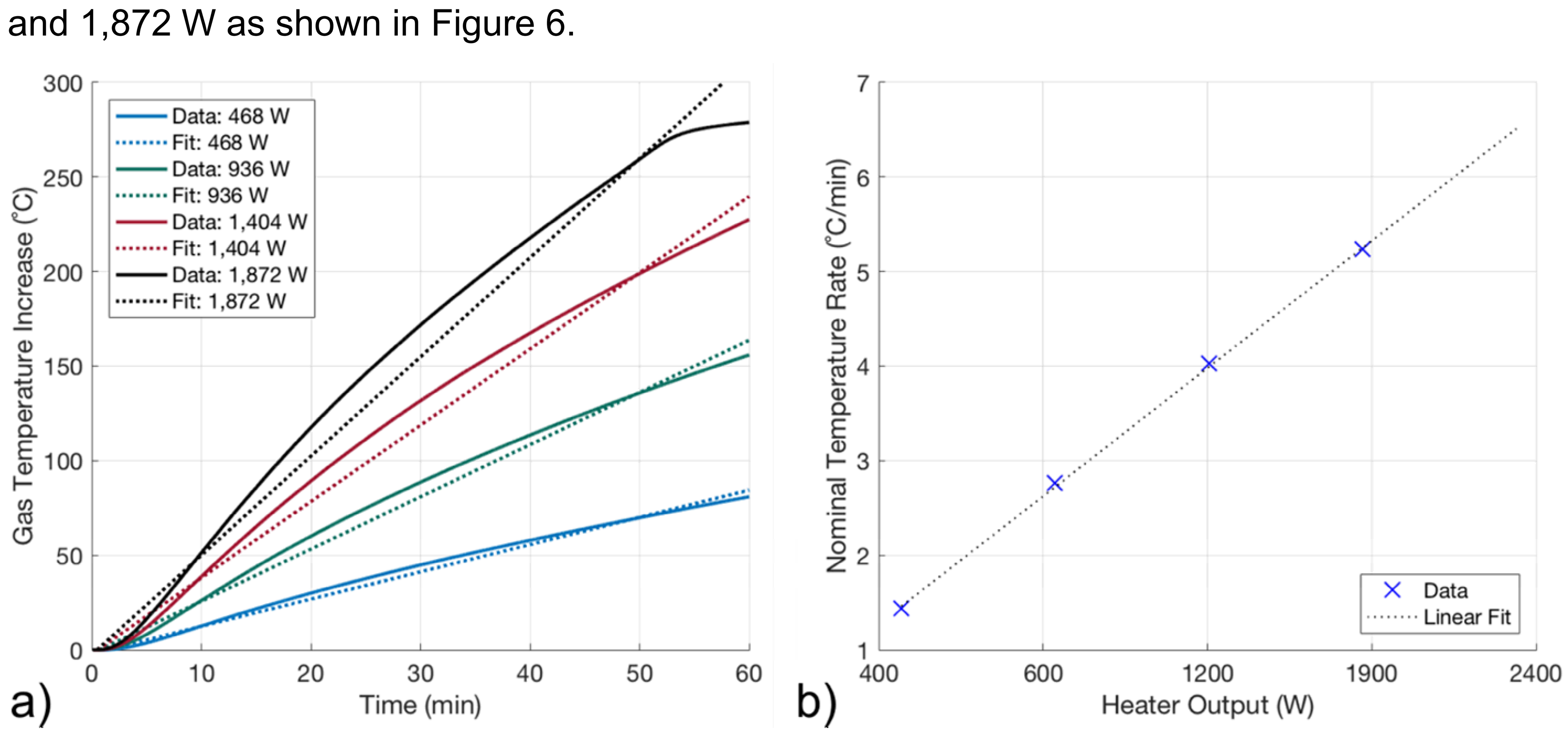


Figure 6: Calibrations of (a) gas temperature and (b) nominal rate

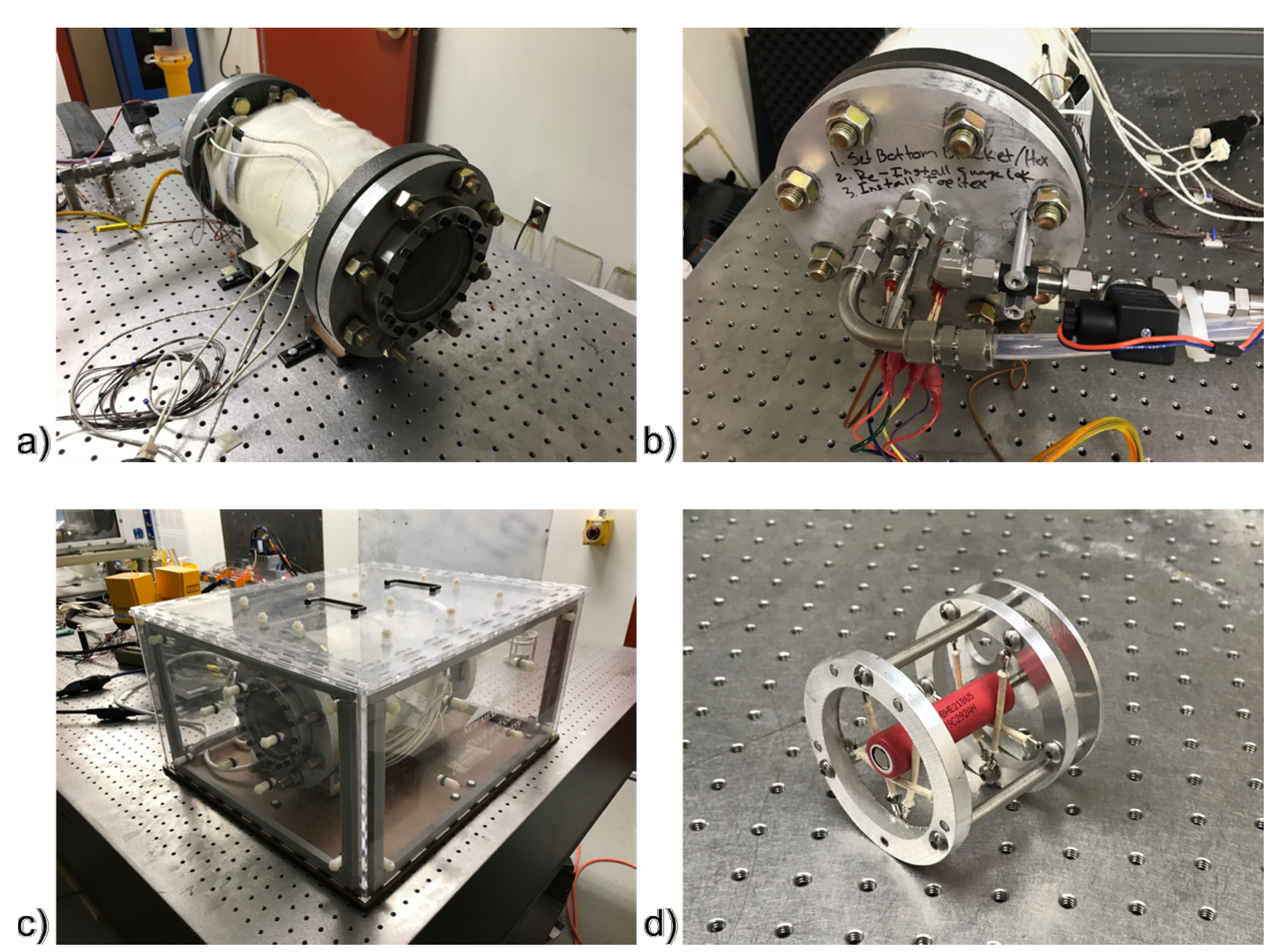


Figure 7: (a) The test chamber with viewing window, (b) instrumentation cap with a thermocouple probe, data lines, gas purge tubing, and chamber pressure transducer, (c) insulation structure, and (d) battery holder.

References and Acknowledgements

- [1] Mier et. al., Overcharge and thermal destructive testing of lithium metal oxide and lithium metal phosphate batteries incorporating optical diagnostics, J. of Energy Storage 13C (2017) pp. 378-386

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Dr. Michael J. Hargather ♦ Associate Professor of Mechanical Engineering ♦ EMRTC Research Scientist ♦ michael.hargather@nmt.edu ♦ www.nmt.edu/mjh