

Lithium Battery Update

The Effect of State of Charge On
Flammability and Propagation of
Thermal Runaway

Presented to: Systems Working Group

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Federal Aviation
Administration



The Effect of State of Charge On Flammability

- **Groups of rechargeable lithium-ion 18650 cells were tested in two modes.**
 - Heated using an external alcohol flame
 - 7 cells wired together
 - Cone calorimeter
 - 5 separate tests with 1 cell at each charge, 20%, 30%, 50%, 70%, 100%
 - *heat flux of 50 kw/m²*



The Effect of State of Charge On Flammability

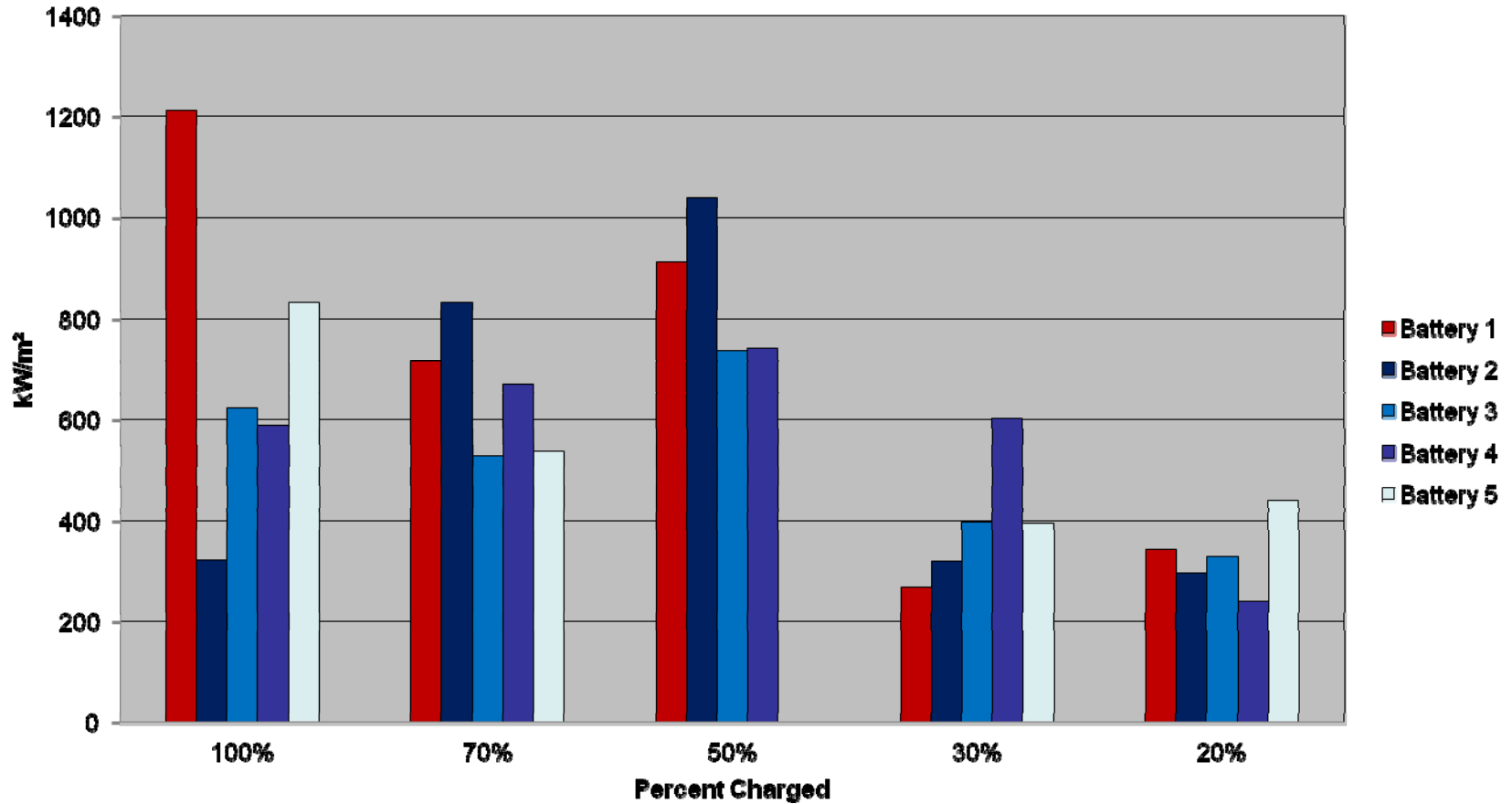


The Effect of State of Charge On Flammability

- **Results: Heated Using External Flame**
 - 100% Charge: produced flammable electrolyte, large pressure pulse, strong torching fire, sparks, vent 4:00 minutes, ignition of electrolyte 4:28
 - 50% Charge: produced flammable electrolyte, large pressure pulse, vent 3:46 minutes, ignition of electrolyte 4:56 minutes
 - 30% Charged: produced flammable electrolyte, small pressure pulse, vent 3:39 minutes, ignition of electrolyte 5:07 minutes



Peak Heat Release Rates For Different Charges



Cone-Calorimeter 100% charged Test



Cone-Calorimeter 30% Charged Test



Effect of State of Charge On Flammability – 100%



The Effect of State of Charge On The Propagation of Thermal Runaway

- **Tests were designed to measure the effect of state of charge on the propagation of thermal runaway**
 - 4 cells were wired together in line
 - A 100 Watt Cartridge Heater was secured to the first battery as the heat source



The Effect of State of Charge On The Propagation of Thermal Runaway

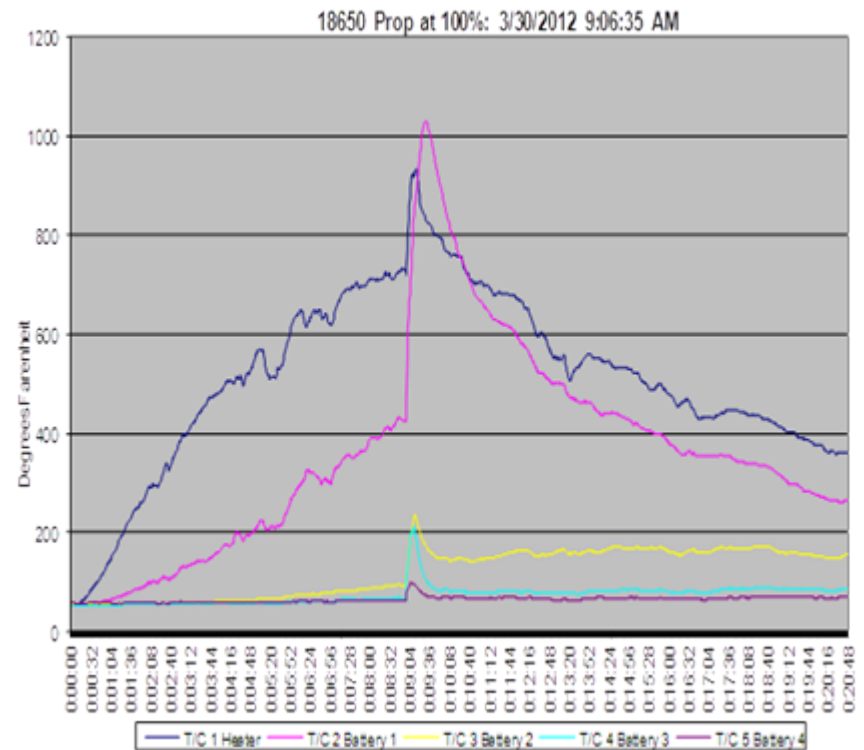
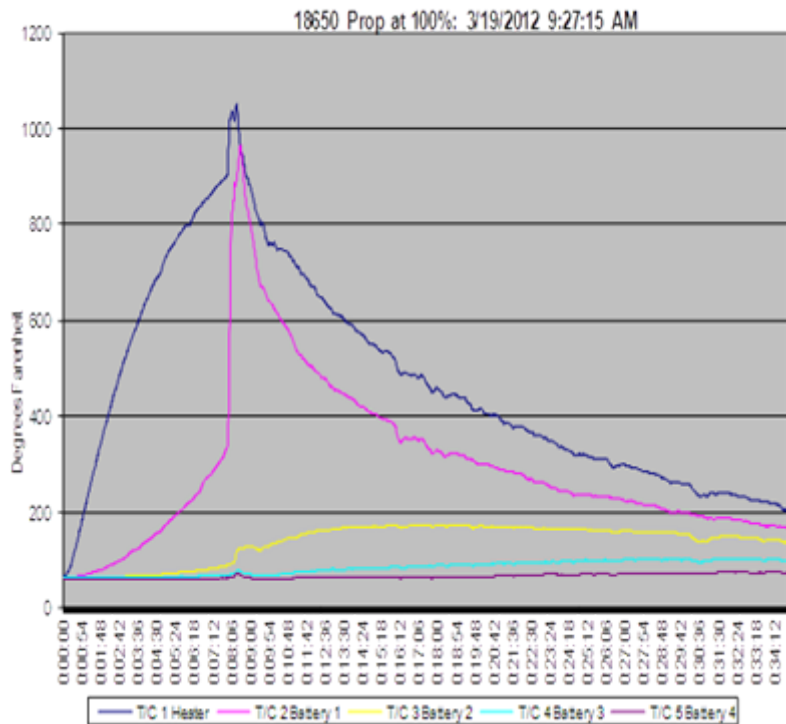
- **A series of 5 tests were conducted; 100%, 50%, 40%, 30%, 20% charge**
- **5 thermocouples (one for the heater and one for each corresponding battery) recorded the temperatures**



Propagation Test Configuration

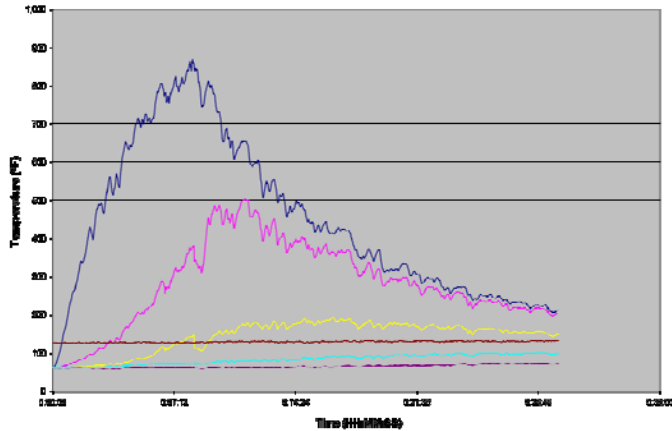


Propagation Test Data

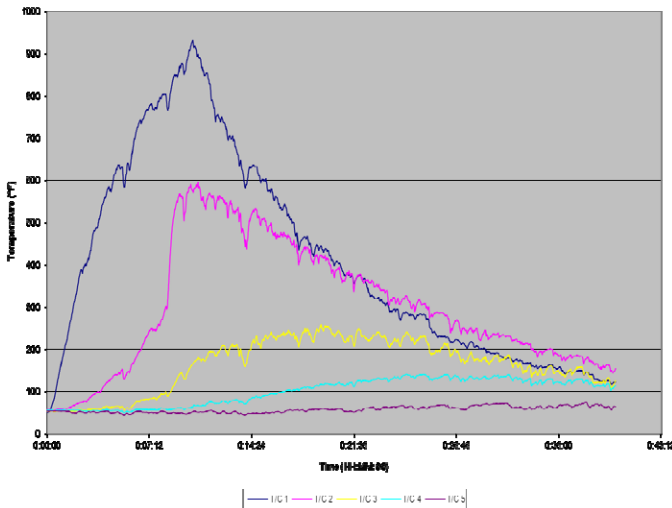


Propagation Test Data

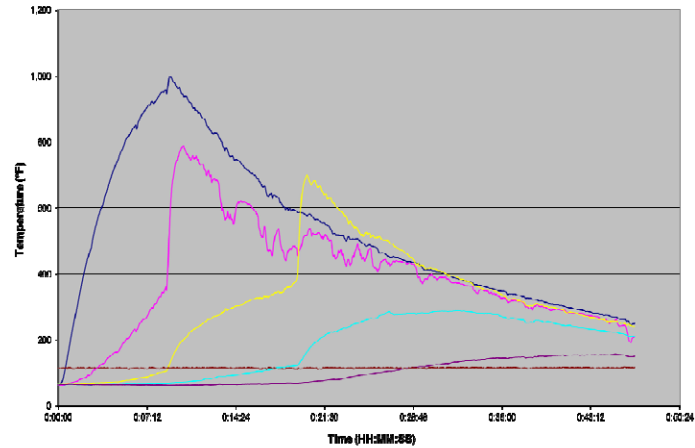
Propagation of 16650 Cells at 30% Charge



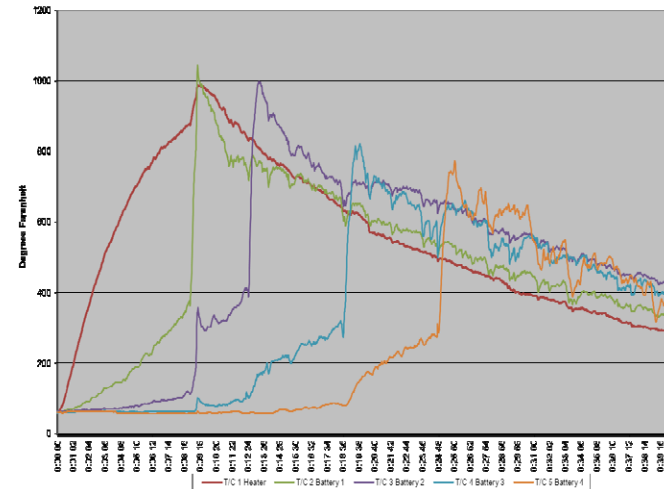
Propagation Test: LG 16650 Cells @ 30% Charge



Propagation of 16650 Cells at 40% Charge



Propagation of 16650 Cells at 50% Charge



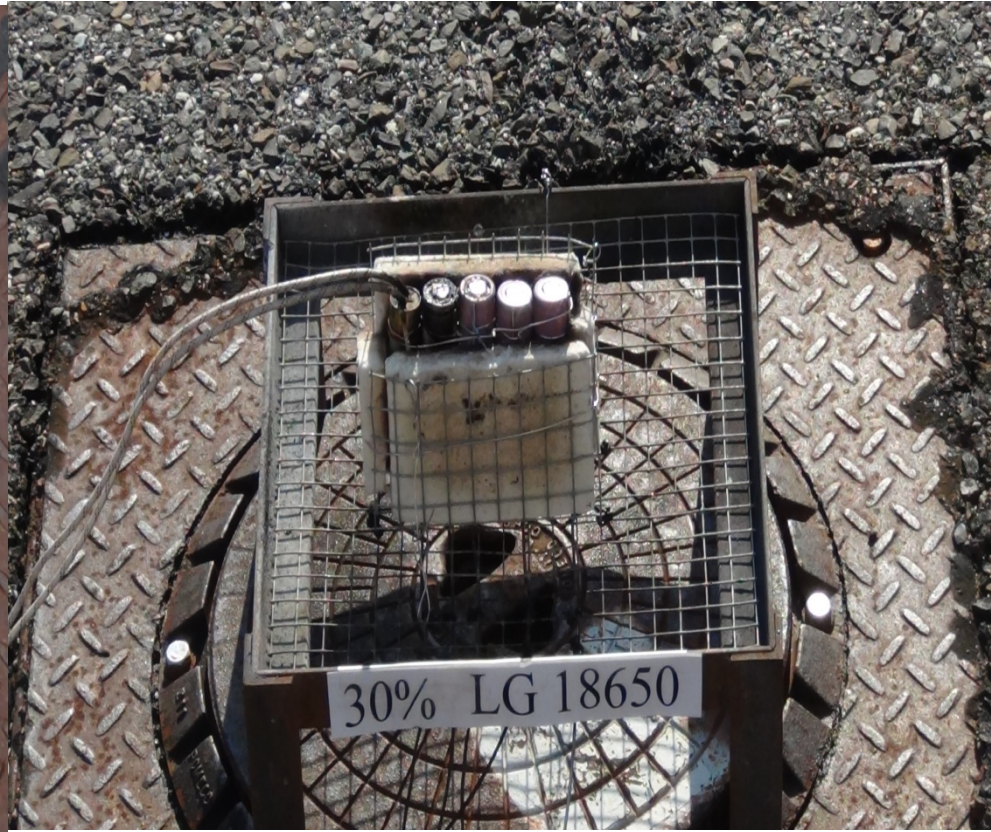
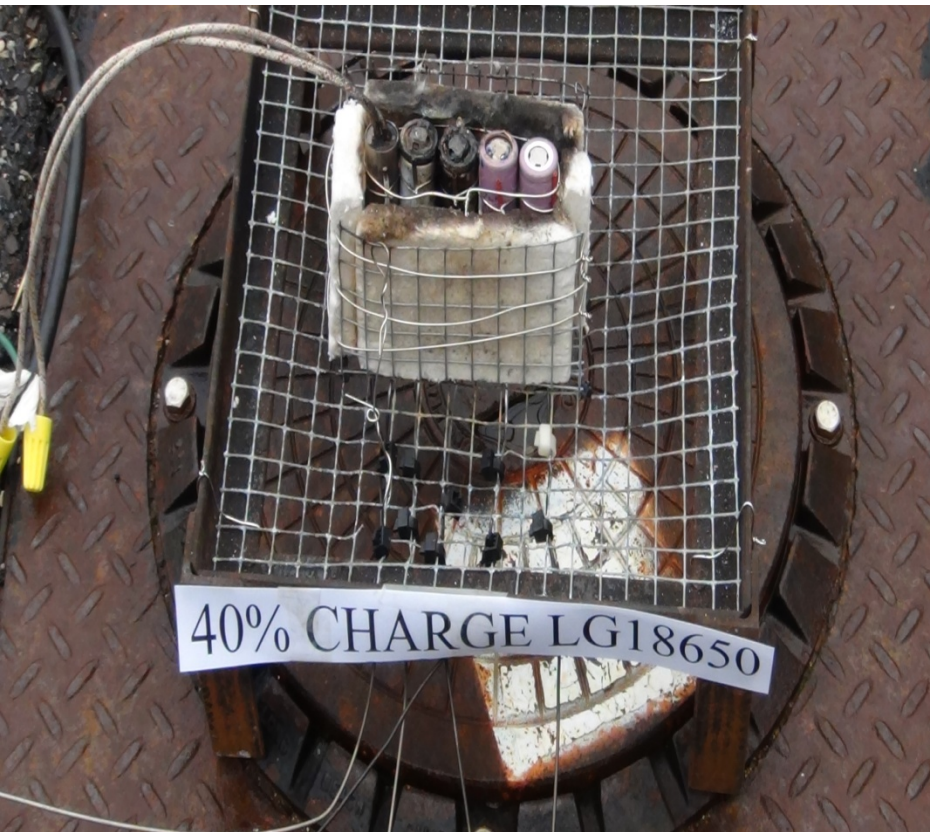
The Effect of State of Charge On The Propagation of Thermal Runaway



The Effect of State of Charge On The Propagation of Thermal Runaway



The Effect of State of Charge On The Propagation of Thermal Runaway



The Effect of State of Charge On The Propagation of Thermal Runaway

- **Results**

- 100% Battery exploded in both tests, rapid cooling was observed. Peak temperature: 1030°F
- 50% test consumed all cells. Peak temperature: 1044°F
- 40% 2 cells were consumed, peak temperature 760°F decreased after thermal runaway in cell 2.
- 30% venting occurred in battery 1 with no thermal runaway. Peak temperature: 560°F
- 20% venting occurred with a peak temperature 502°F



The Effect of State of Charge On The Propagation of Thermal Runaway

- **Conclusions**

- 50% charge produces the greatest possibility of thermal runaway propagation
- 30% or less charge halts the propagation of thermal runaway
- Heat release values decrease with reduced states of charge
- Shipping cells at less than 50% state of charge may reduce the severity of a fire event



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