HBK Technology Days – Virtual Seminar Series

Tuesday, November 8, 2022

Lifetime Test

Capture lithium-ion battery cell key characteristics by cell testing and validation

Presented by Dr. Patrick (Peng) Xiao,
Lead Engineer – Battery Cell Chemistry,
Jaguar Land Rover

Capture Lithium-ion Battery Cell Key Characteristics By Cell Testing & Validation

Abstract

As the evolution of the cell is moving fast forward with advanced chemistry, formats, capturing the key characteristics of the cell's performance becomes critical to cell integration into the Pack. Those key characteristics include cell's fundamental performance such as capacity, DCIR, cycle life & storage life as well thermal properties, safeties under extreme use conditions or abuse conditions. A suite of characterization is introduced how Jaguar Land Rover cell team are capturing those key characteristics as the cell testing & validation methods. Those key characteristics are providing a full spectrum of the information of cells' interfaces in the Pack.

About the presenter, Dr. Patrick (Peng) Xiao, Lead Engineer – Battery cell chemistry, Jaguar Land Rover

Dr. Peng Xiao, also known as Patrick Xiao in Jaguar Land Rover. Patrick Xiao works in Jaguar Land Rover as a Battery Cell Technology & Design Technical Specialist in Advanced Cell Engineering team in 2017. He looks at that cell's interfaces within the Pack for cell integration, DFMEA, cell testing & validation, cell safety, and cell ageing. He also had the experience of Pack attributes, cooling system design, BMS control in an excursion working experience in McLaren.

Patrick Xiao has a Ph.D. in chemical in Nanyang Technological University, specializing in electrochemistry. He also worked in CATL for cell design and prototype cell manufacturing of HEV and BEV cells before he joined Jaguar Land Rover.

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08-11-2022

Dr Peng (Patrick) Xiao
Advanced Cell Engineering, Jaguar Land Rover

Hello, I am P. Xiao

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022

BSc, Material Science in Physics
Topic: Solid Oxide Fuel Cell

Ph.D
Chemical Engineering
Thesis: Molybdenum based material for electrochemical application

Research Associate
Li-O_2 battery, substrate dependant growth of Lithium peroxide

System Engineer
Cell Design, Prototype manufacture in HEV, BEV cells

Lead Engineer
Battery Electrical System in Battery Electrical Module, FPCB

Senior System Engineer
Pack Attributes & Requirements

Lead Engineer/Technical Specilist in Cell Technology
1, Cell DFMEA
2, Cell safety

Battery in the lab

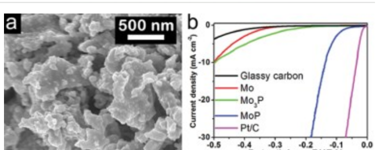
ADVANCED FUNCTIONAL MATERIALS

Full Paper
Novel Molybdenum Carbide–Tungsten Carbide Composite Nanowires and Their Electrochemical Activation for Efficient and Stable Hydrogen Evolution
Peng Xiao, Xiaoming Ge, Haibo Wang, Zhaolin Liu, Adrian Fisher, Xin Wang

From the journal:
Energy & Environmental Science

Molybdenum phosphide as an efficient electrocatalyst for the hydrogen evolution reaction†

Peng Xiao, Mahasin Alam Sk, Larissa Thia, Xiaoming Ge, Rern Jern Lim, Jing-Yuan Wang, Kok Hwa Lim and Xin Wang

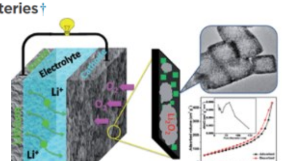


ADVANCED ENERGY MATERIALS

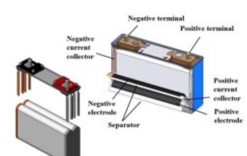
Review
A Review of Phosphide-Based Materials for Electrocatalytic Hydrogen Evolution

From the journal:
Journal of Materials Chemistry A

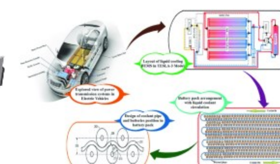
Facile synthesis of hierarchical porous Co_3O_4 nanoboxes as efficient cathode catalysts for Li-O_2 batteries†

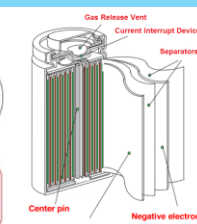


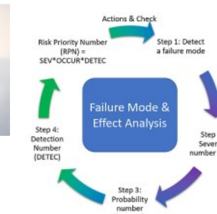
Battery industrialization



Battery on the road







A typical customer might say they are looking for…

Comfort
Good handling
Luxury
Fast charging
Speed
Safety
Low cost
The 'right feel'
A spacious interior
Beauty
Long range

☆ Understand your customer

Now how do we create this?

☆ Understand your customer's environment

The vehicle attributes *in the eyes of the customer* must first be translated into a series of *metrics, values and measurables*, which can then be engineered.

Vehicle Concept
- 0-60 acceleration < 3s
- Top speed : 150 mph
- Range: 300 miles

Battery Requirements
- Pack power
- Useable pack energy
- Pack weight
- Pack voltage

System Architecture
- Cell pulse power
- Cell capacity/chemistry
- Cell voltage

Implementation
Cell testing & characterisation:
- Electrical Performance
- Thermal properties
- Lifetime
- Safety
- Mechanical robustness

- Cell electro-thermal model
- Battery plant model
- Ageing model

Models should show high confidence that the design will meet the vehicle requirements

System Integration
- Module/pack testing
- Thermal control
- BMS
- Electrical electronics

Design Validation
- Engineering vehicles built
- Durability testing
- Data constantly fed back into models

Operation & Maintenance
- Final modifications before vehicle production

Verification

The battery is designed from top-level vehicle requirements.

The design is then tested extensively at the cell, module, pack and vehicle level.

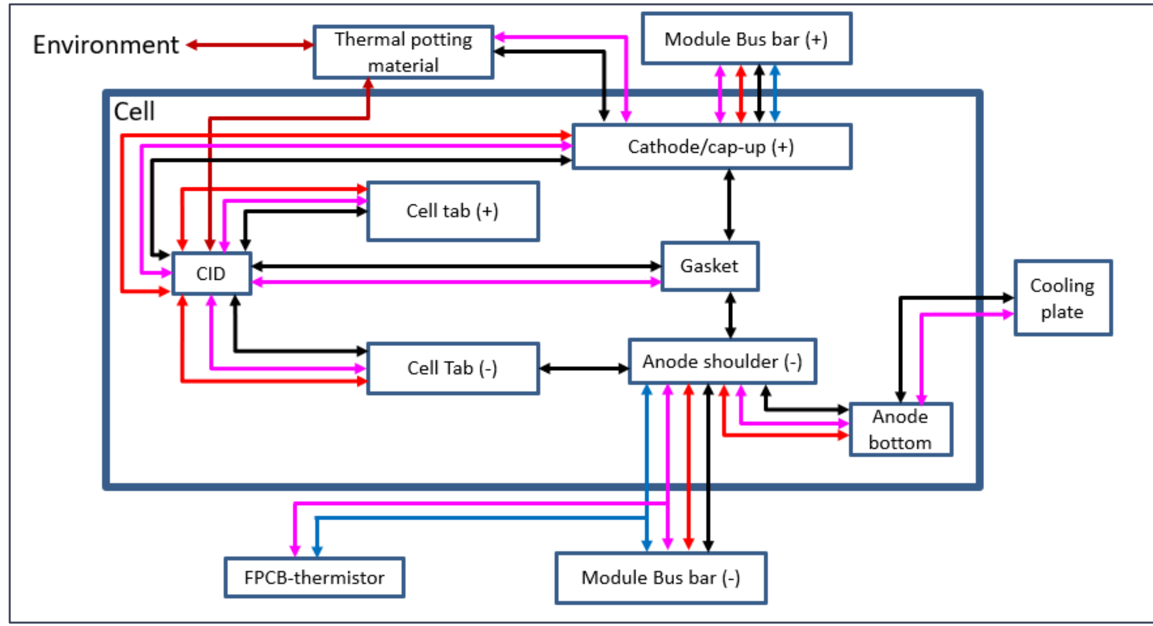
P: Physical contact, spatia (fixation, tolerance)

E: Electrical interface

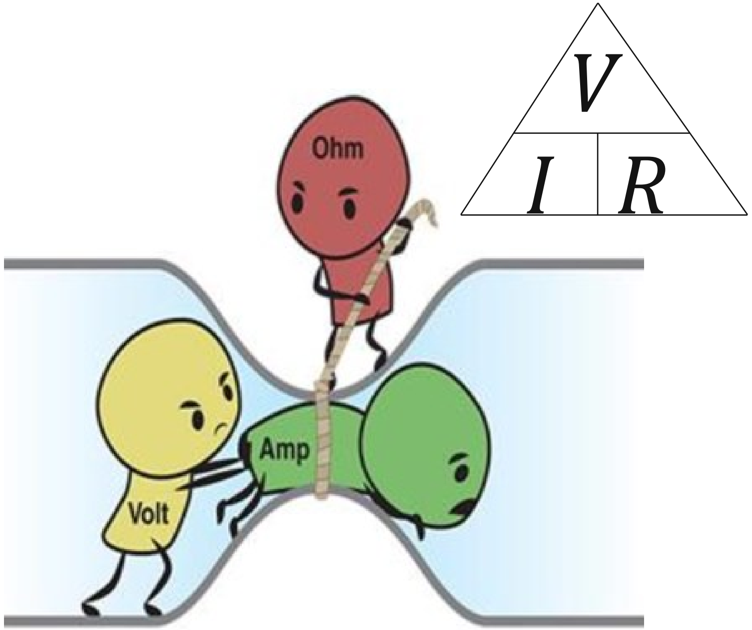
H: Thermal interface

I: Information interface

M: Material exchange

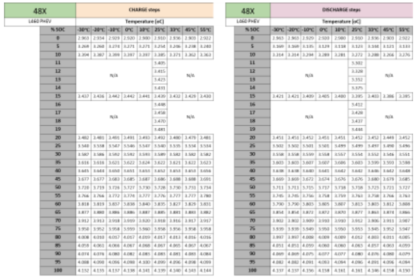


Mechanical interface | Electrical interface | Thermal interface | Information interface | Material interface



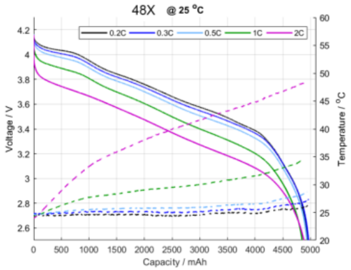
Electrical Test

OCV vs. SoC



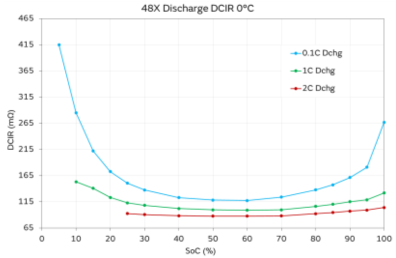
- Characterise the relationship between Open Circuit Voltage and State of Charge as function of temperature.
- Vital for the BMS SOC measurement algorithm.

Rate Capability



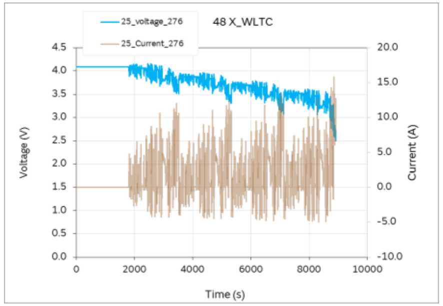
Measure the capacity, energy, average voltage of the cell as a function of c-rate and ambient temperature.

HPPC



Characterise the power capability of the cell by mapping its DCIR as a function of C-rate, SoC, pulse duration and ambient temperature.

Drive Cycles



Vehicle-level drive cycles as power traces are translated to cell level and applied to cells. The voltage response and heat generation are used to validate the cell electro-thermal model.

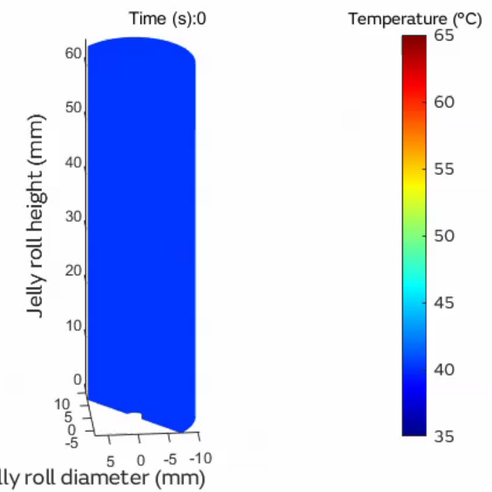
Performance test data provides crucial information about the cell's capabilities under various conditions. Most importantly, it is used to produce electro-thermal models and look-up tables for the vehicle BMS

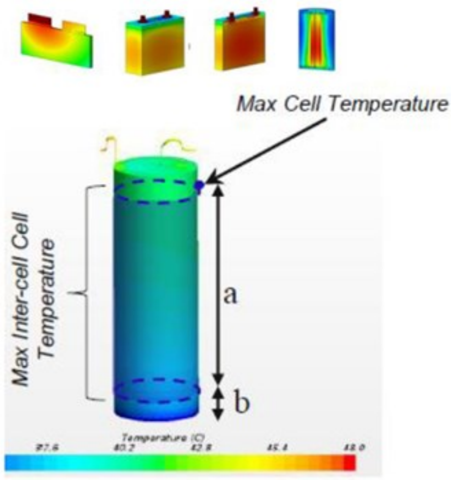
Thermal

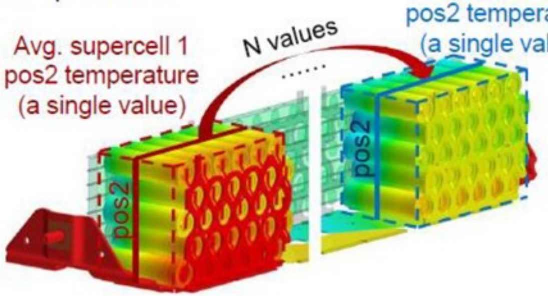
What is the temperature difference between the cell's surface and cell's core?

What is the acceptable temperature gradient of a cell on the surface?

What is the acceptable temperature gradient of the cells in the Pack?

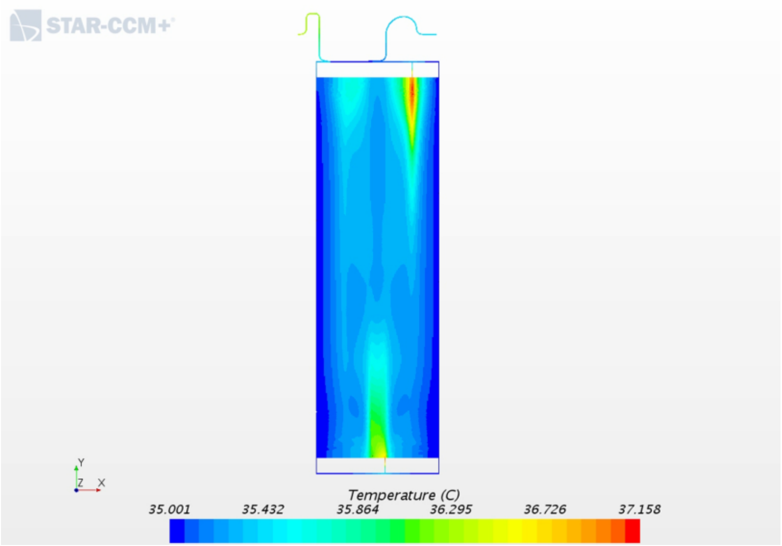




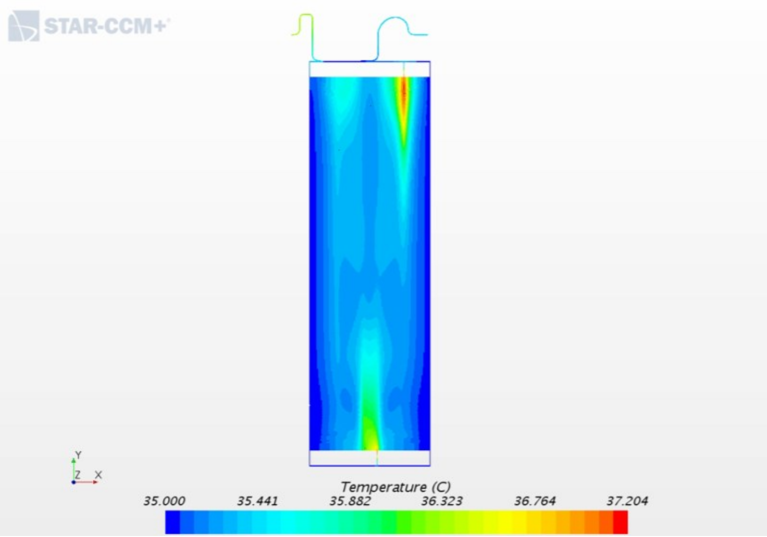


Simulation To Explore Cooling Strategies

Side cooling	Bottom cooling



Side/radial cooling 600s 13.3A 35 °C coolant

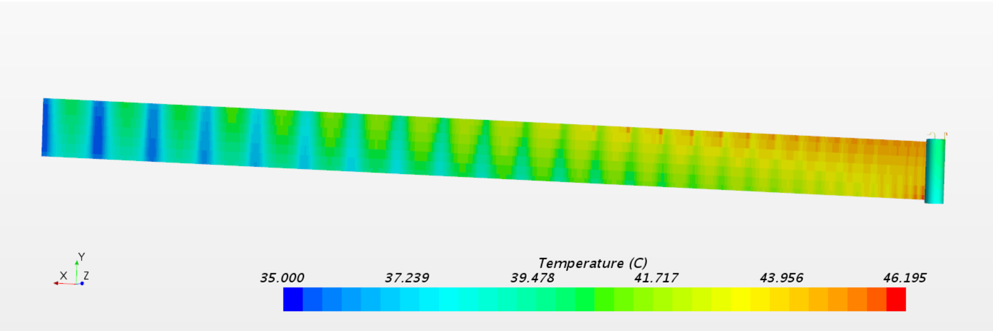


Bottom/axial cooling 600s 13.3A 35 °C coolant

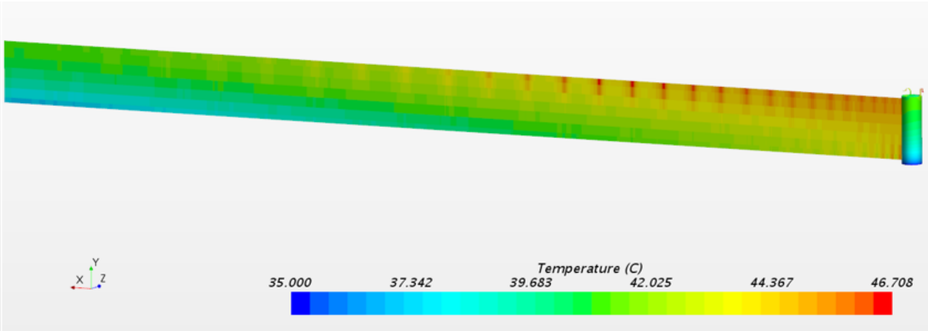
Simulation shows ~ 1 °C difference

Temperature Gradient – unrolled Jelly roll

Side cooling



Bottom cooling

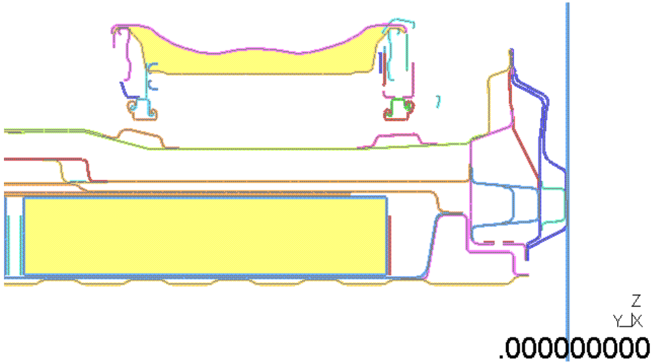


Mechanical Test

Mechanical shock

Vibration

Side pole test



Simulation indicates how much head room the Pack has before the deformation reaches cell

The level of safety design margins:

1. Vehicle level: Side pole presents no failure mode
2. Pack level: 100 kN or 30% deformation
3. Cell level: 100 kN or 1000 times of the cell weight, or 15 % deformation

Mechanical Protection on Cell From Being Impacted

Over Charge

Charge at 1C (A); stop testing when the battery management system becomes operated, or the following conditions are reached:
1.1x end-of-charge voltage OR SOC = 120%

Over Discharge

Discharge at 1C (A); stop testing when the battery management system becomes operated, or the following conditions are reached:
< 25% of the rated voltage. OR Over-discharge time exceeds 30 min.

Over Current

Gradually increase the battery charge/discharge current; stop testing when the battery management system becomes operated, or the following conditions are reached:
Exceeding the maximum current limit by 20% OR The temperature reaches the maximum temperature limit.

External Short Circuit

Short cut the connection end of test object for **10 min.**
Short circuit resistance is no more than 20 mΩ, Observe for 2 h.

Safety/Abuse Tests

https://www.theguardian.com/technology/2017/jan/23/samsung-blames-faulty-batteries-for-causing-galaxy-note-7-fires

https://www.nytimes.com/2016/09/13/business/as-more-devices-board-planes-travelers-are-playing-with-fire.html

https://www.nytimes.com/2013/11/20/business/us-safety-agency-opens-inquiry-into-tesla-fires.html

Abuse tests to cover extreme use cases and low-possibility incidents → Safety Device → Dashboard to flag warning, e.g., no voltage detection, high temperature, etc. →

Prevention | Design Failing Pathway | Detection

No hazards in the vehicle or before occupants leave the vehicle

Fire

The test object is exposed directly to the flame (gasoline pan) for 130 seconds.

Crush

100kN or the crush deformation reaches 30% of the overall, Maintain 10 min.

Vibration

TPJLR-47
GB/T
ECE R100

Turn Over

Turn battery pack in x-axis a full 360° at 6°/s, then rotate it in increment of 90° and rest for 1hr between each increment until a full rotation is made.

Mechanical Shock

Impose semi-sinusoidal shock wave in z-axis 3 times. Magnitude of 25g and 15ms. Observe for 2 hrs

Crash

TPJLR
FMVSS
GB/T

Temperature Shock

Alternating temperature environment of (-40 ± 2)°C to (85 ± 2)°C. Kept in each extreme temperature for 8h, and perform 5 cycle.

Salt Spray

Spray the salt mist for 2h. Store for 20h ~22h at 40 ± 2°C, RH 93 ± 3% repeat three times. Store for three cycles at 23 ± 2°C, relative humidity 45% ~ 55%. Repeat above 4 times.

Altitude

4,000m or equivalent height of the pressure conditions, leave for 5h. Discharge at 1C (A) (no more than 400 A) constant current to the discharge cut-off voltage.

High temperature

At maximum operating temp, perform the charge/discharge test at max current of the battery until: battery temperature exceeds the maximum operating temp by 10°C OR The maximum temperature change within 1h is less than 4°C.

Low Temperature

@Tmin-5°C; initiate charging; stop testing when the battery management system becomes operated or: Charging over 30s OR The temperature is higher than the lower charge temperature limit.

Drop

Position the battery so that the lowest part of it is 4.9m high from the floor. Drop the battery (free-fall) onto a concrete floor.

Thermal Propagation

Overcharge, Nail or Over-temperature initiation. 5 minutes before flame or smoke visible outside of pack.

Immersion/Soak

Immerse in a solution of 3.5%NaCl (mass fraction; at 25°C) for 2 h. The water shall be sufficient to totally immerse the pack. Observe for 2 h.

Hot and Humid Cycle

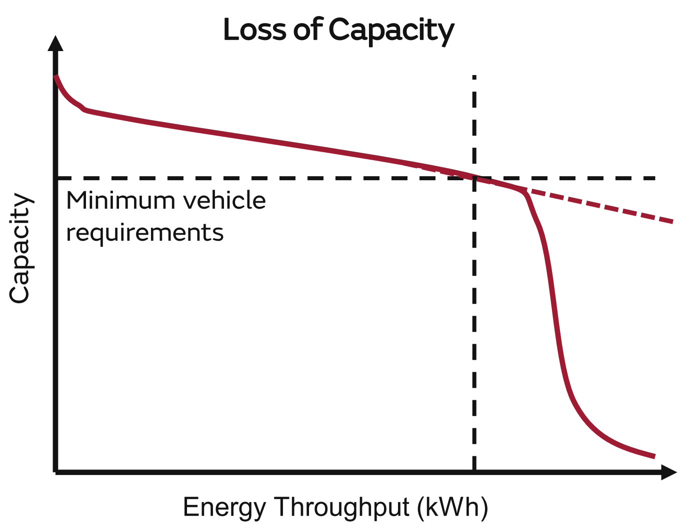
The highest temperature is +55°C and up to 100% humidity, proceed with 5 cycles. Observe for 2h.

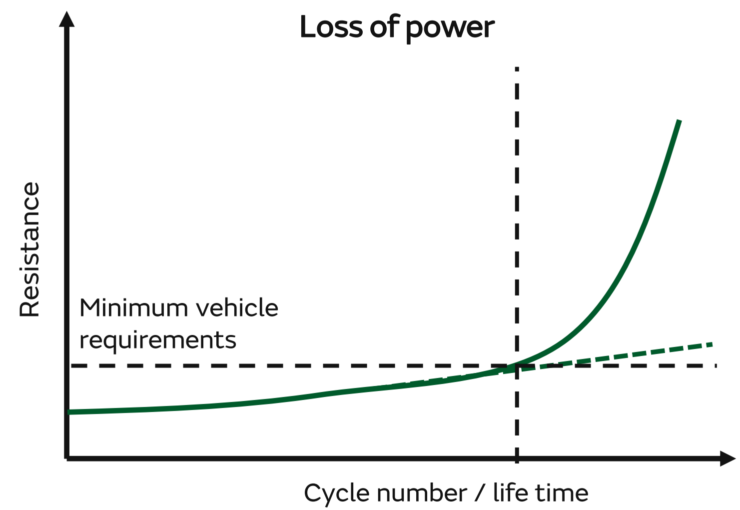
Lifetime Test

State of Health (SoH) - as the battery ages, the available capacity decreases. SoH is the available capacity expressed as a percentage of the full capacity from new.

SoH can also be expressed as:

- Internal resistance: the capability to deliver power
- Capacity : the capability to deliver range





Ageing Factors

- SOC
- Temperature
- C-rate
- Voltage
- ⋮
- Other Contributing Damaging Factors

Ageing Mechanisms

- Li Plating
- Electrolyte Oxidation/ Reduction
- Current Collector Corrosion
- Material Isolation
- ⋮...
- Material Phase Change
- Particle Cracking
- Gas Evolution
- Binder Decompositi on
- Other

Ageing Effects

- Cyclable Li Loss
- SEI Growth
- Cell physical effects

EoL Judgement

- Capacity Loss
- Internal Resistance Rise

Vehicle Attributes

- Capacity
- Power Delivery (Discharge)
- Power Acceptance (Charge)
- Performance in Low and Hot Climates
- ⋮
- Other Attributes

Impact on User Application

- Range / Refuel /Recharge Frequency
- 0-60 Acceleration Time
- Charge Time / Miles per Minute
- Peak Regen Capability
- Fast Charge Capability
- Cruise Time (130kph / Vmax)
- Other Effects
- LifeTime / Warranty

Summary

1. Battery Pack development process – V-diagram
2. To deliver all the attributes for the vehicle, Jaguar Land Rover covers those cell level tests:
   1. Electrical tests
   2. Thermal test
   3. Mechanical tests
   4. Safety/abuse tests
   5. Life time test - SoH

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ACKNOWLEDGES TO

All team members in Cell team in Jaguar Land Rover LTD

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