NASA Aerospace Battery Workshop

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EAS Company History (Innovation since 1996)

April 1996

Foundation of GAIA Akkumulatorenwerke GmbH at Nordhausen

Development of cell portfolio of large cylindric cells for hybrid electric applications based on a unique electrode production technology using NCA and LFP chemistries.

September 2011

Foundation of Joint Venture EAS Germany GmbH (Shareholders GAIA 40% & HAWKER GmbH 60%)

August 2012

EAS Germany GmbH fully owned by HAWKER GmbH / Enersys

January 2015

Frazer Nash new owner of EAS Germany GmbH

June 2017

Merger of GAIA and EAS Germany via asset deal into EAS Batteries GmbH with MONBAT as new owner

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Cylindrical Cells

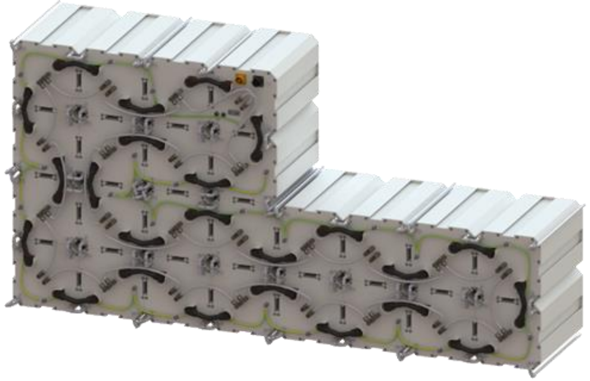
Diameter: 168 mm
Length: 210 mm

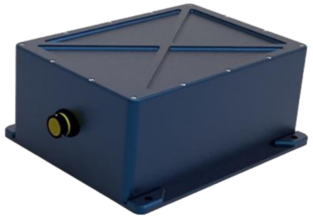
Diameter: 46 mm
Length: 90 mm

Diameter: 34 mm
Length: 144 mm

Diameter: 60 mm
Length: 203 mm

Battery Systems





Development Services

From idea to product

- Cell development (material, jelly roll, mechanical design)

- Custom Battery Solutions

- Analysis & Testing

Cell example

HP602030 LFP 40

40 Ah LFP Lithium Ion Battery Cell

High Power Cell
3.2 V / 128 Wh

The lithium iron phosphate battery cell **HP602030 LFP 40** is ideally suited for applications requiring high power density, high charge and discharge rates and very safe operation.

Features and Benefits

- Very safe cell chemistry
- Robust stainless-steel casing avoids corrosion and provides shock resistance for harsh environment applications
- Ultra-high maximum pulse discharge to meet exceptional peak demands
- M12 terminals for easy assembly and low resistance interfaces
- Suitable for low temperature operation
- Made in Germany
- UN 38.3 certified

Mechanical Characteristics

Diameter	60	mm
Length	232	mm
Length without terminals	203	mm
Weight	1.3	kg
Volume	0.57	l

Chemical Characteristics

Cathode	Lithium Iron Phosphate (LFP)
Anode	Graphite

Electrical Characteristics

Maximum capacity @ 1 C @ 25 °C	42	Ah
Nominal capacity @ 1 C @ 25 °C	40	Ah
Nominal operating voltage	3.2	V
Charging voltage	3.5	V
Recommended cut-off discharge voltage	2.5	V
Energy	128	Wh
Discharge current @ 25 °C		
Recommended	80	A (2 C)
Maximum continuous	800	A (20 C)
Maximum pulse (2 s)	1,600	A (40 C)
Low temperature performance	See Chart	
AC impedance (1 kHz)	< 0.3	mΩ
DC resistance (2 s pulse @ 20 C / 50 % SoC)	< 0.7	mΩ
Specific energy	99	Wh/kg
Energy density	223	Wh/l
Specific power		
Continuous discharge @ 20 C / 50 % SoC	1,750	W/kg
2 s pulse discharge @ 40 C / 50 % SoC	2,400	W/kg
Power density		
Continuous discharge @ 20 C / 50 % SoC	3,900	W/l
2 s pulse discharge @ 40 C / 50 % SoC	5,400	W/l

Applications and Markets

- Hybrid electric drives
- Electric drives
- Load leveling and peak shaving
- Boosting and range extension
- Space
- Aerospace
- Defense
- Marine
- Heavy duty vehicles
- Off-Road vehicles
- Rail and transport
- Mining

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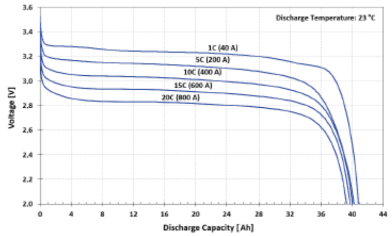
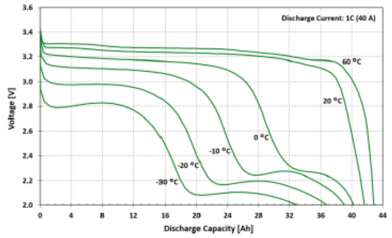
Operating Conditions

Recommended charging method	Constant Current/ Constant Voltage
Recommended charging voltage	3.5 V (max. 3.6 V)
Recommended continuous charging current	40 A (1 C)
Maximum continuous charging current	120 A (3 C)
Maximum pulse charge current (15 s) (max. 70 % SoC, average current < 120 A)	320 A (8 C)
Absolute lower voltage limit for discharge	
Continuous @ 20 C (-30 °C to 60 °C)	2.0 V
Pulse @ 40 C (-30 °C to 60 °C)	1.5 V
Storage and transport conditions	25 to 50 % SoC
Maximum temperature range	-40 °C to 60 °C
Recommended temperature range	10 °C to 25 °C
Operating temperature	
Discharge	-30 °C to 60 °C
Charge (recommended)	-10 °C to 40 °C
Cycle life @ 20 °C (EoL @ 80 % of nominal capacity)	
100 % DoD, 2 C	> 5,000 cycles
80 % DoD, 2 C	> 6,250 cycles





Latest cell example

UHP601300 LFP 22

22 Ah LFP Lithium Ion Battery Cell

Ultra-High Power Cell
3.2 V / 70 Wh

The lithium iron phosphate battery cell **UHP601300 LFP 22** is ideally suited for applications requiring ultra-high power density, ultra-high charge and discharge rates and very safe operation.

Features and Benefits

- Very safe cell chemistry
- Robust stainless-steel casing avoids corrosion and provides shock resistance for harsh environment applications
- Ultra-high maximum continuous discharge to meet exceptional peak demands
- M12 terminals for easy assembly and low resistance interfaces
- Suitable for low temperature operation
- Made in Germany
- UN 38.3 certified

Mechanical Characteristics

Diameter	60	mm
Length	159	mm
Length without terminals	130	mm
Weight	0.9	kg
Volume	0.37	l

Chemical Characteristics

Cathode	Lithium Iron Phosphate (LFP)
Anode	Graphite

Electrical Characteristics

Maximum capacity @ 1 C @ 25 °C	24	Ah
Nominal capacity @ 1 C @ 25 °C	22	Ah
Nominal operating voltage	3.2	V
Charging voltage	3.5	V
Recommended cut-off discharge voltage	2.5	V
Energy	70	Wh
Discharge current @ 25 °C		
Recommended	44	A (2 C)
Maximum continuous	880	A (40 C)
Maximum pulse (2 s)	1,320	A (60 C)
Low temperature performance	See Chart	
AC impedance (1 kHz)	< 0.3	mΩ
DC resistance (2 s pulse @ 20 C / 50 % SoC)	< 0.7	mΩ
Specific energy	78	Wh/kg
Energy density	189	Wh/l
Specific power		
Continuous discharge @ 40 C / 50 % SoC	2,550	W/kg
2 s pulse discharge @ 60 C / 50 % SoC	3,760	W/kg
Power density		
Continuous discharge @ 40 C / 50 % SoC	6,200	W/l
2 s pulse discharge @ 60 C / 50 % SoC	9,150	W/l

Applications and Markets

- Hybrid Electric Drives
- Electric Drives
- Load Leveling & Peak Shaving
- Boosting & Range Extension
- Space
- Aerospace
- Defense
- Marine
- Heavy Duty Vehicles
- Off-Road Vehicles
- Rail and Transport
- Mining

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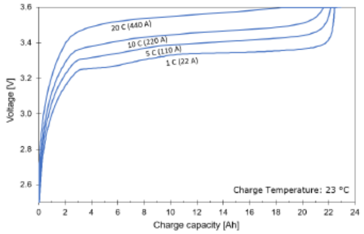
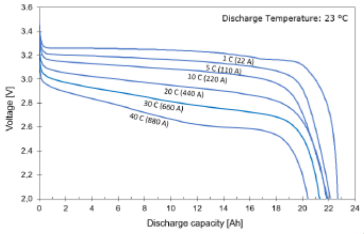
Operating Conditions

Recommended charging method	Constant Current/ Constant Voltage
Recommended charging voltage	3.5 V (max. 3.6 V)
Recommended continuous charging current	22 A (1 C)
Maximum continuous charging current	440 A (20 C)
Maximum pulse charge current (15 s) (max. SOC 70 %, average current < 220 A)	660 A (30 C)
Absolute lower voltage limit for discharge	
Continuous @ 40 C (- 40 °C to 60 °C)	2.0 V
Pulse @ 60 C (- 40 °C to 60 °C)	1.5 V
Storage and transport conditions	25 to 50 % SoC
Maximum temperature range	- 40 °C to 60 °C
Recommended temperature range	10 °C to 25 °C
Operating temperature	
Discharge	- 40 °C to 60 °C
Charge (recommended)	- 25 °C to 40 °C
Cycle life @ 20 °C (EoL @ 80 % of nominal capacity)	
100 % DoD, 2 C	> 5,000 cycles
80 % DoD, 2 C	> 6,000 cycles
100 % DoD, 5 C	> 2,400 cycles
80 % DoD, 5 C	> 3,000 cycles





What we are working on

Under development

UHE461200 NMC 59

59 Ah NMC Li-ion Battery Cell

High Energy Cell
3.75 V, 222 Wh

The lithium-ion battery cell UHE461200 NMC 59 is ideally suited for applications requiring ultra high energy density.

Features and Benefits

- Ultra high energy density
- Continuously tabbed design
- Good cooling properties
- Low resistance
- Made in Germany

Mechanical Characteristics

Cell design	cylindrical	
Diameter	46	mm
Length	120	mm
Weight	555	g
Volume	200	ml

Chemical Characteristics

Cathode	Lithium nickel manganese cobalt oxide (NMC)
Anode	Silicon composite (SiC)

Electrical Characteristics

Nominal capacity	59	Ah
Charging voltage	3.75	V
Specific energy	402	Wh/kg
Energy density	1115	Wh/l

Operating Conditions

Discharge current @ 25 °C	
Recommended	30 A (0.5C)
Maximum continuous	177 A (3C)
Maximum pulse (2 s)	295 A (5C)
Recommended continuous charging current	30 A (0.5C)
Maximum charging current	177 A (3C)
Operating temperature	
Discharge	- 30 °C to 60 °C
Charge (recommended)	- 10 °C to 40 °C
Cycle life @ 20 °C (EoL @ 80 % of nominal capacity)	
100 % DoD, 0.5C	> 500 cycles
80 % DoD, 0.5C	> 600 cycles

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Under development

UHP461200 LFP 12

12 Ah LFP Li-ion Battery Cell

Ultra-High Power Cell
3.2 V, 38 Wh

The lithium ion battery cell UHP461200 LFP 12 is ideally suited for applications requiring ultra-high power, ultra-high charge and discharge rates, very safe operation and long cycle life.

Features and Benefits

- Ultra-high power
- Safe LFP chemistry
- Continuously tabbed design
- Good cooling properties
- Low resistance
- Made in Germany

Mechanical Characteristics

Cell design	cylindrical	
Diameter	46	mm
Length	120	mm
Weight	450	g
Volume	200	ml

Chemical Characteristics

Cathode	Lithium Iron Phosphate (LFP)
Anode	Graphite

Electrical Characteristics

Nominal capacity	12	Ah
Charging voltage	3.2	V
Specific energy	85	Wh/kg
Energy density	190	Wh/l

Operating Conditions

Discharge current @ 25 °C	
Recommended	24 A (2C)
Maximum continuous	420 A (35C)
Maximum pulse (2 s)	840 A (70C)
Recommended continuous charging current	12 A (1C)
Maximum continuous charging current	180 A (15C)
Operating temperature	
Discharge	- 30 °C to 60 °C
Charge (recommended)	- 10 °C to 40 °C
Cycle life @ 20 °C (EoL @ 80 % of nominal capacity)	
100 % DoD, 2C	> 5,000 cycles
80 % DoD, 2C	> 6,250 cycles
100 % DoD, 5C	> 2,500 cycles

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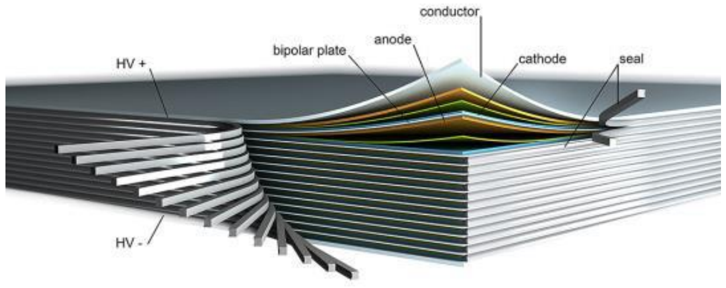
EAS Extrusion Technology

- The present EAS process to manufacture the electrodes is a three-step process consisting of pre-mixing, extrusion and lamination. Simple, fast, environmentally-friendly (no NMP is used), and resulting in high-quality products.
- The components of the active electrode layer, active material, binder, and conductive additive, are mixed in a dry state without solvent addition.
- The powder is fed into a heated twin-screw extruder followed by the addition of EC as a plasticizer. In the extruder, the components are mixed extensively, and pressure is built up to squeeze the mixture though a nozzle to form a layer of the materials that is sandwiched between two polymer carrier foils. In order to secure a constant quality, a calendar (to ensure constant thickness of the extrudate) and a beta-gauge (to measure the mass per unit area of the extrudate) are used.
- The extrudate is slit to the active width of the electrode and then laminated to both sides of the current collector, which is a little wider to achieve a mass-free strip for contacting. The EC is evaporated by heating the electrode in a short drying tunnel by IR.

EAS Extrusion Technology

The EAS extrusion-based electrode process has several advantages over commonly used wet coating:

- The area used for machines is small due to a very short drying tunnel and subsequent the energy use is significantly lower.
- The equipment can be operated in a dry room allowing the processing of moisture sensitive electrode materials.
- EC as plasticizer has a low vapor pressure and low toxicity (traces remaining after drying are not critical). It is a component of electrolytes and compatible with all used active materials.
- There is no binder migration during drying which avoids performance reducing binder accumulation at the electrode surface.
- Thicker electrodes while slurry coating faces adhesion problems at loadings above 4 to 5 mAhcm-2, EAS extrusion technology can produce these loading with identical recipes and perfect adhesion. Electrodes up to 6 mAhcm-2were successfully produced but the upper limit was not yet reached, loadings up to 10 mAhcm^{2}are conceivable without doubts.
- The EAS drying lane has a length of 1.5 m and the drying times usually range between 20 s and 1 min depending on the material and electrode loadings.
- The free-standing extrudate allows for novel electrode concepts such as bipolar plates.

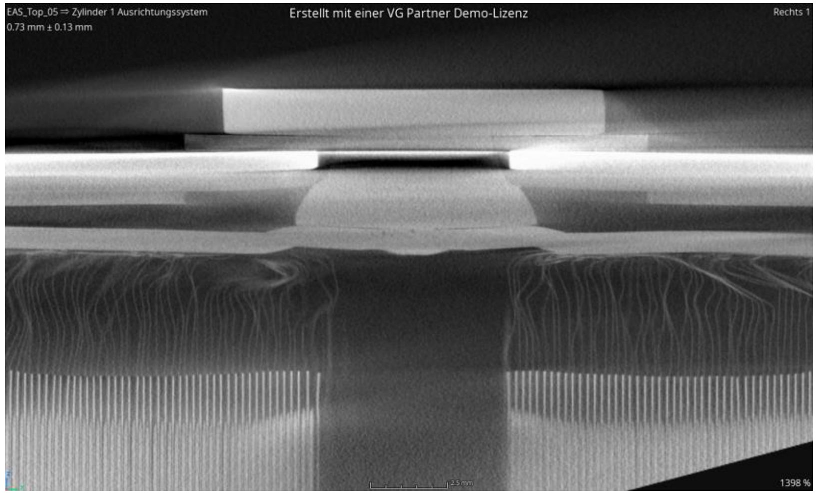


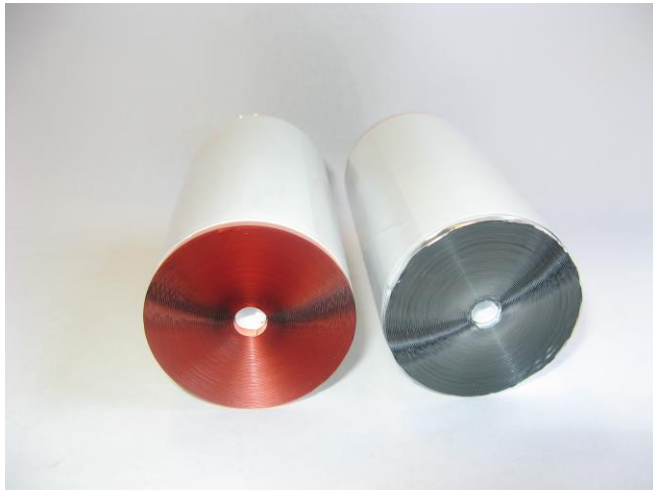
EAS Vent Design

- Notching in the cap (EAS IP in dimension and geometry) on the opposite side of the terminal
- Opening pressure ≈ 20 ± 2 bar (could be adjusted to the requirements)

EAS Tabless Contacting Technology

- A contact disc is laser welded flat onto the protruding mass-free strip of the anode on one and the cathode on the other side .
- This technology is an enabler for high power in large cylindrical cells.
- The unique EAS laser contacting technology is protected by EAS Patent DE 10 2017 006 229.3.





EAS Tabless Contacting Technology

EAS Tabless Laser Contacting	Tabbing	Advantage of EAS
Mass-free strip parallel to electrode	Mass-free strip perpendicular to electrode	Faster electrode coating
-	Removal of mass before tabbing	Additional production step for mass removal not required
-	Tab welding either before or during winding	Either additional production step or slower winding process
Welding contact plate to jelly roll	-	Separate high-speed process. Enables fast winding of large diameter jelly rolls
		Lower impedance through large number of points of contact
		Better utilization of space in cell case

Integration of Metallized Polymer Current Collectors into 46900

Main challenges to overcome:

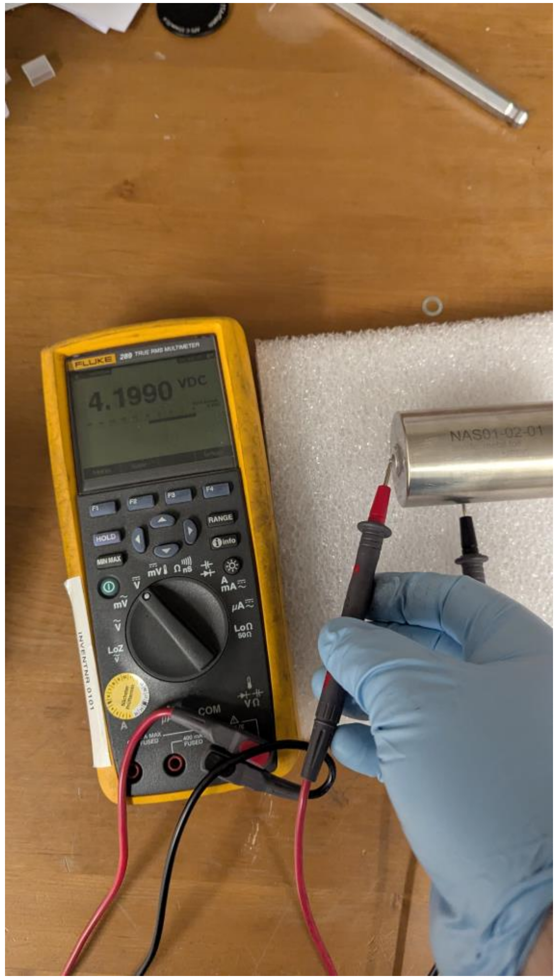
- Increased internal resistance ↘
  - Partially mitigated with the use of EAS tabless contacting
- Contacting metallized polymer current collector to contact disc ↘
  - Successful after optimization of welding parameters and inclusion of additional welding points

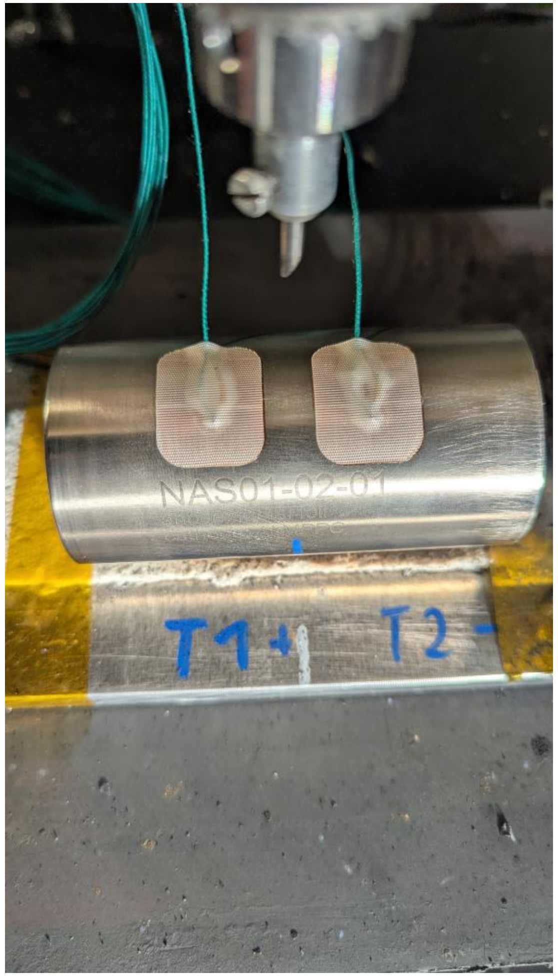
Integration of Metallized Polymer Current Collectors into 46900

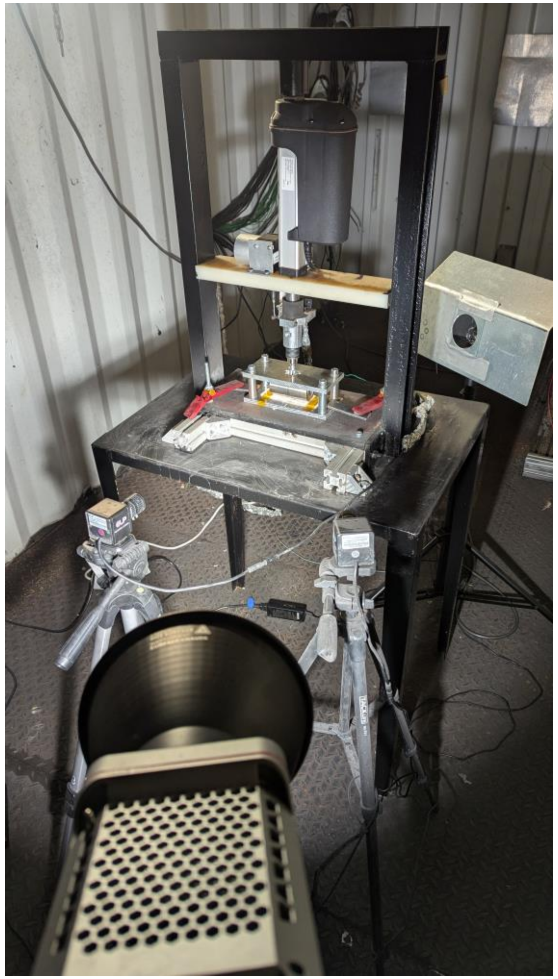
Cell type	1st discharge capacity [Ah]	Irreversible capacity loss [%]	DC resistance [mOhm] 28 A for 10s @ 50% SOC	Impedence 1 kHz [mOhm]	Mass [g]	Specific energy density [Wh/kg]
Standard	28.9	11.34	4.37	1.2	404	257
Al MPCC	28.1	11.73	5.8	2.34	396	255
Al & Cu MPCCs	27.9	11.65	6.41	2.76	381	263

DCR growth from Al MPCC	33%
DCR growth from Al & Cu PCCs	47%

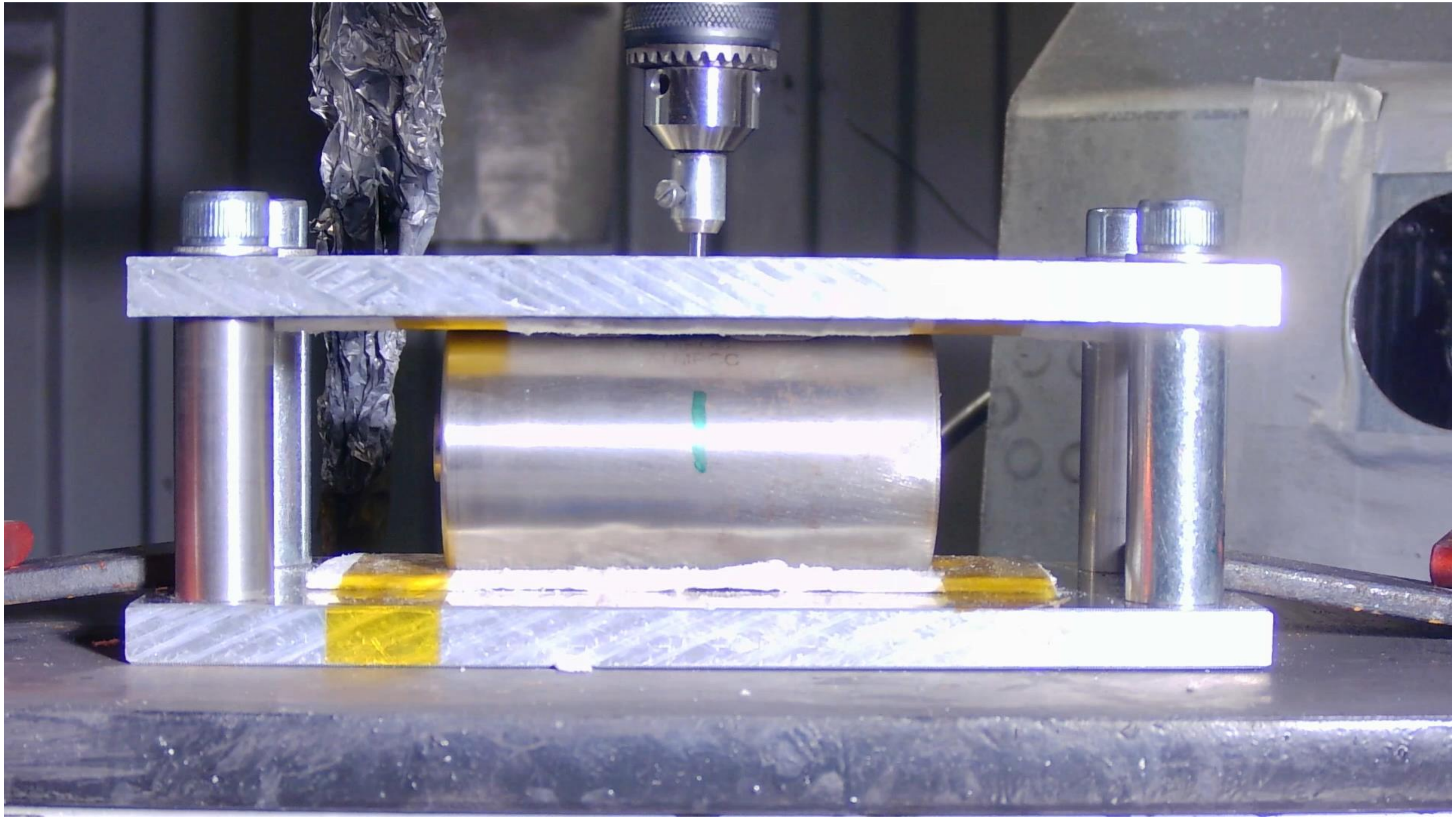
Nail Penetration Test Setup



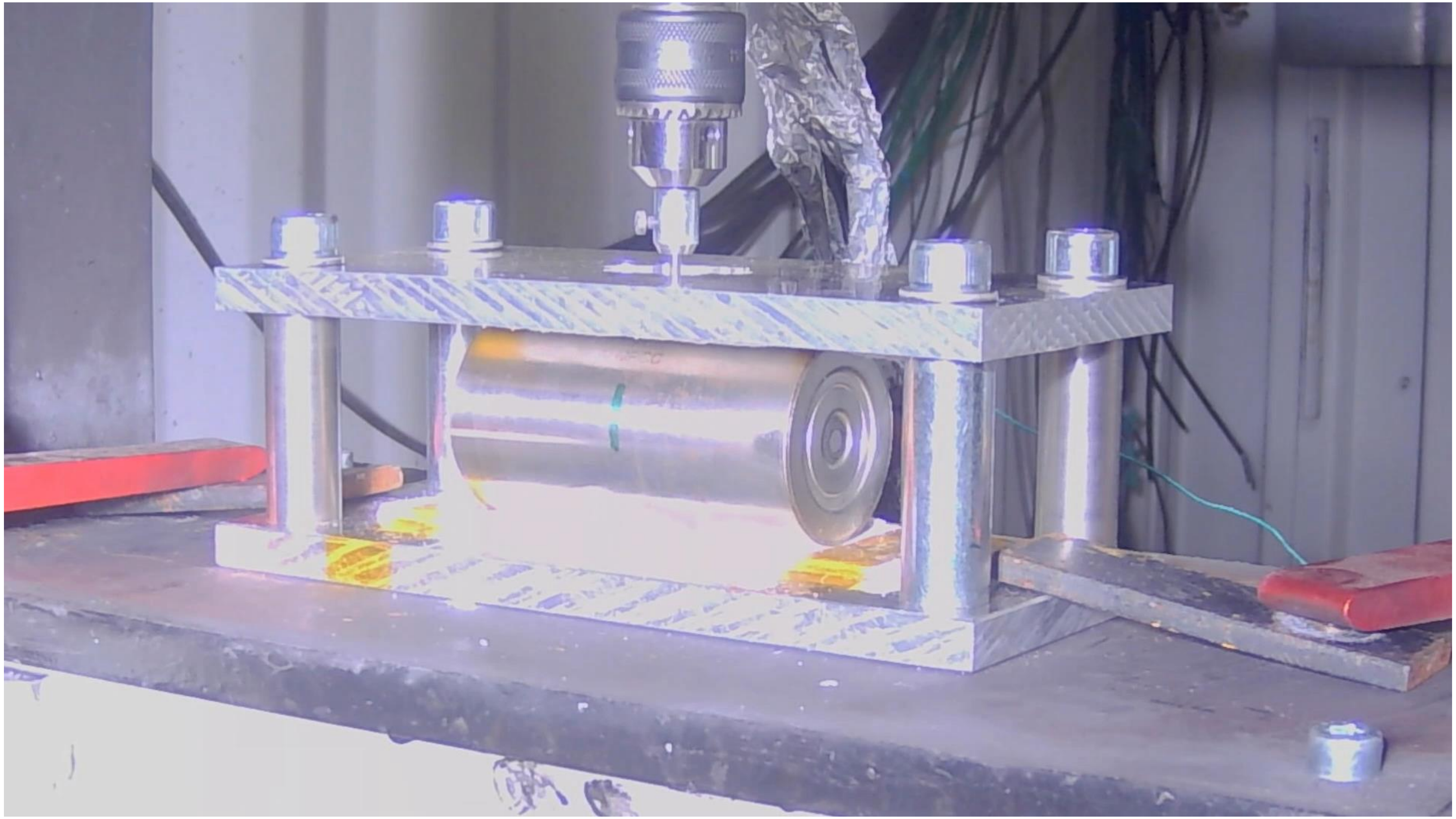




Typical Nail Penetration Test Results – with thermal runaway

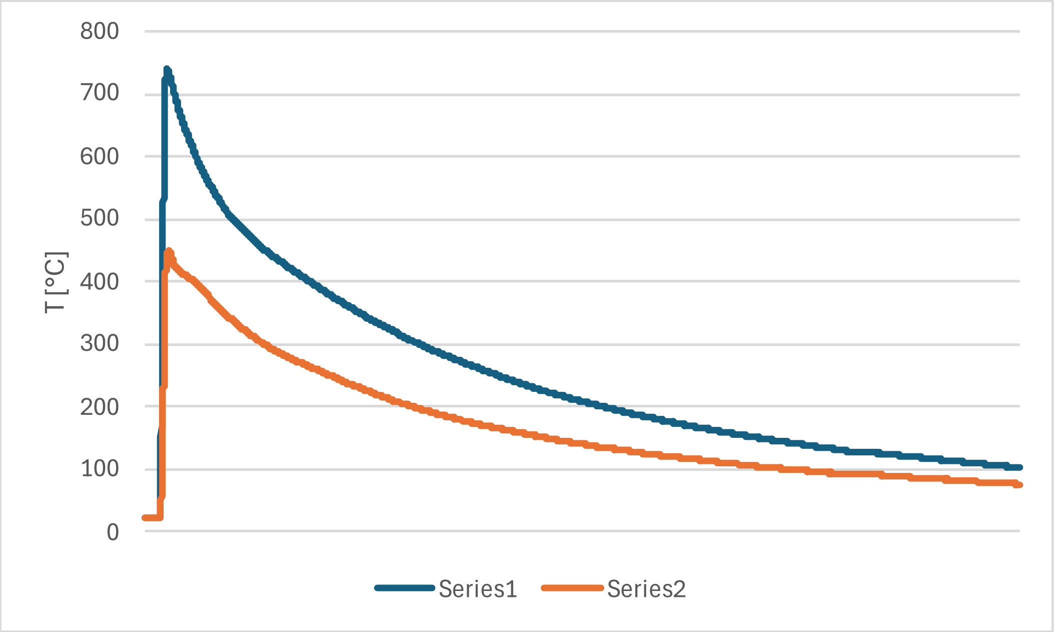


Typical Nail Penetration Test Results – with thermal runaway

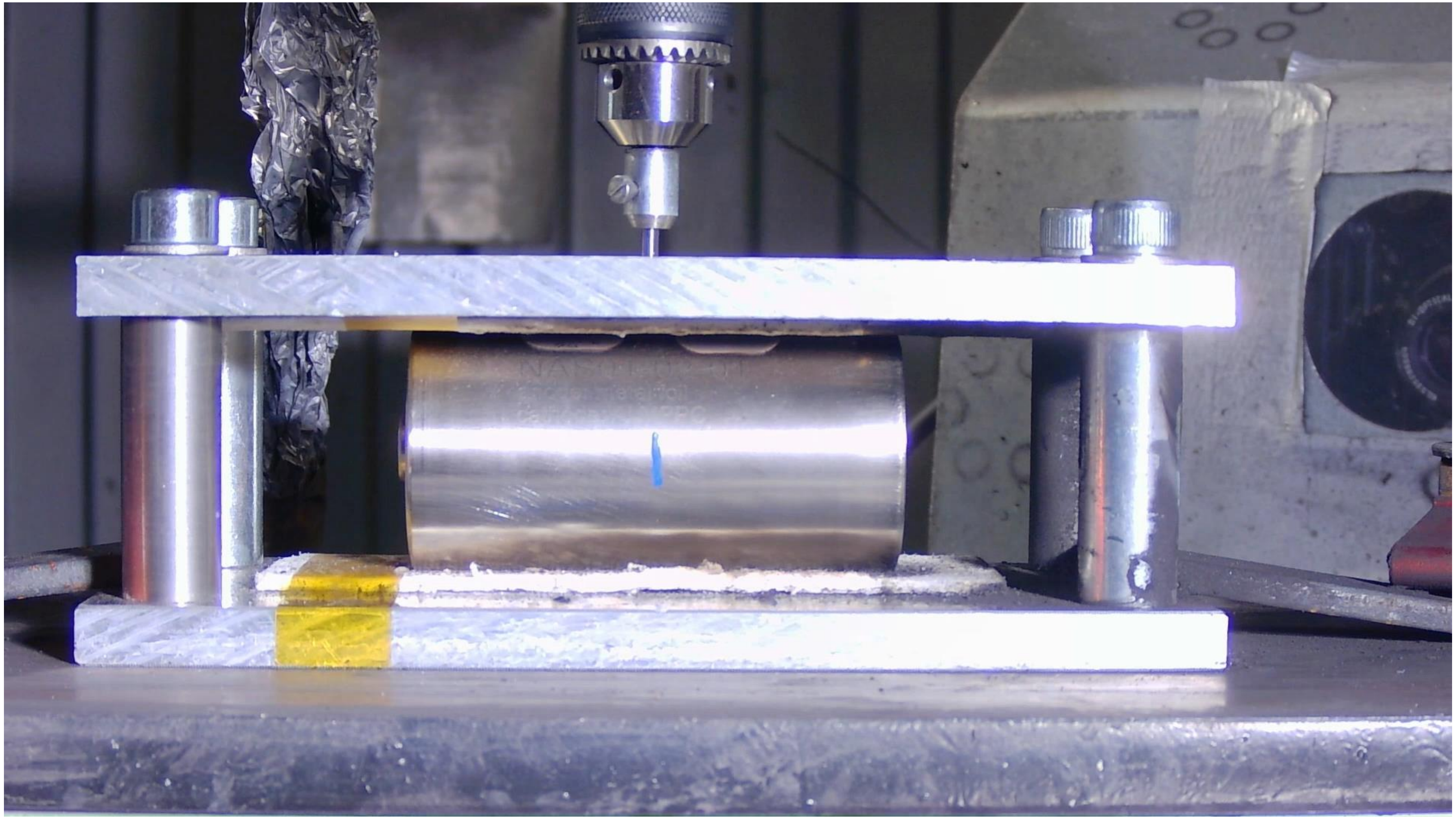


Typical Nail Penetration Test Results

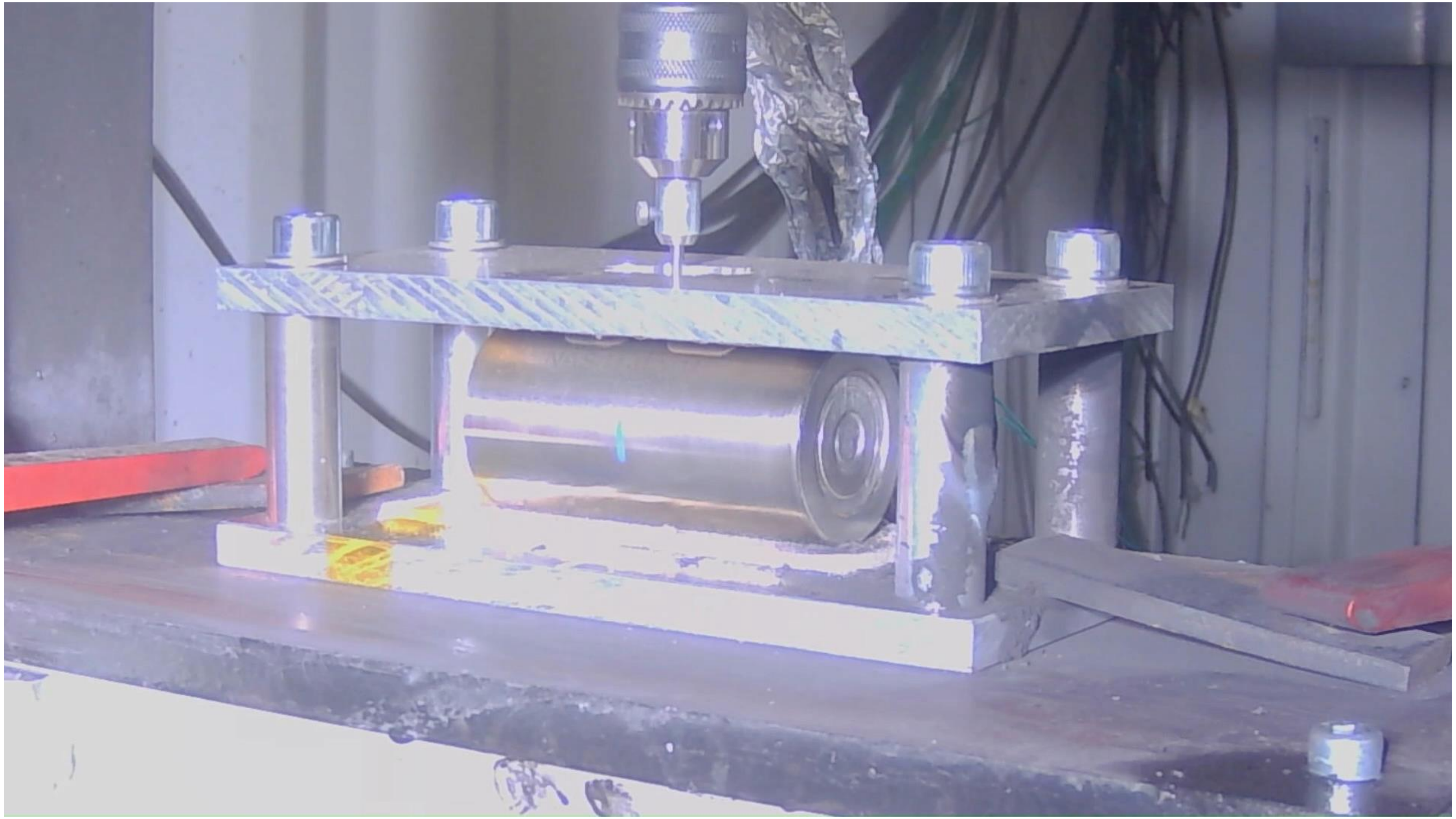
- Gas release followed by a thermal runaway event
- Cell temperature reached >700 °C
- Loss of all voltage and functionality



Nail Test NMC 46900 with Aluminum MPCC – without thermal runaway

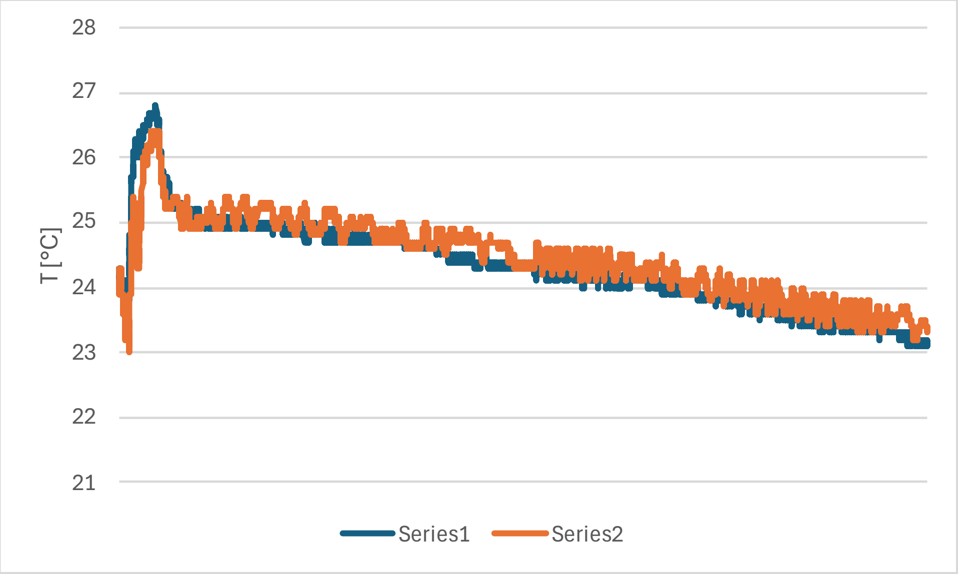


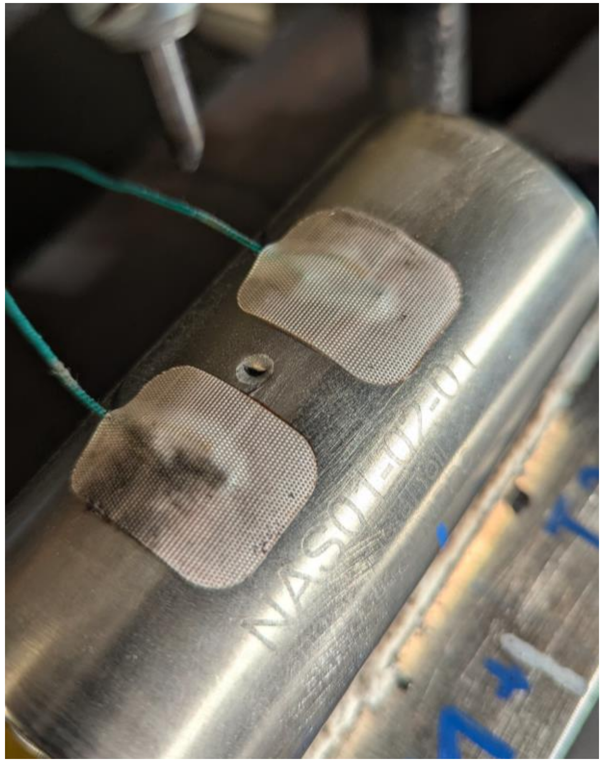
Nail Test NMC 46900 with Aluminum MPCC – without thermal runaway

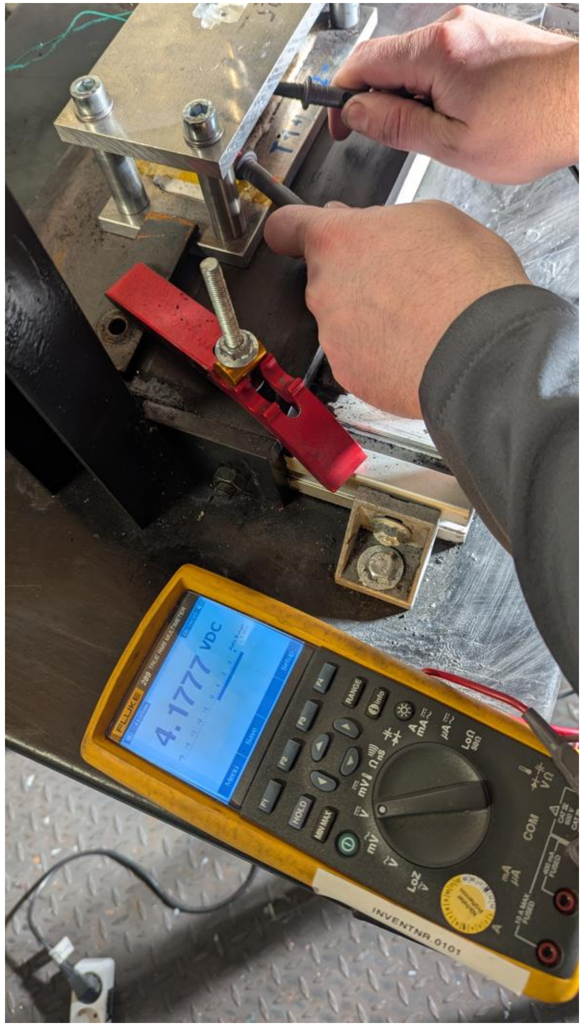


Nail Test NMC 46900 with Aluminum MPCC

- No thermal runaway, even after the nail was removed (test length ~5 minutes)
- Cell had 4.1990 VDC before nail penetration, 4.1777 VDC after
- Max cell temperature reached <27 °C







Beyond the horizon

- Further tests, such as overcharge, to validate safety improvements.
- EAS will build cells with Internal Short Circuit Devices (ISCD) designed for a graphite to aluminum short circuit. If successful, this will enable for easier safety testing.
- It is possible to integrate additional safety elements, such as special separators, to further mitigate any risk of thermal runaway.
- Further development of the extrusion process.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