

University of Wales Trinity Saint David

School of Engineering

Recycling and Second Life of EV Lithium Ion Modules

Major Project

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1 Abstract

With the growing trend of electrification of vehicles as manufactures strive to meet tail pipe CO₂ emissions to reduce fines levied and customer demand. There is an increase in electronic waste (e-waste) and as the most expensive part of a Full PEVs drivetrain is its battery. For the battery to become unserviceable in the vehicle it only needs to see a 20% drop in capacity. Once the capacity drop is enough which could be caused by 1 out of 36 modules the entire battery is replaced, or the vehicle is recycled for most mainstream vehicles. The battery removed may have many modules that can be reused in vehicles or lower power demand applications. The cells within the faulty modules may also have second life applications.

Physical tests were carried out on a sealed cell pouch module. To evaluate the feasibility of removing and reusing cells and recycling faulty cells. Safe practices were researched and described for further work to gain a better understanding of the dangers.

Although the work did not successfully remove the pouches a better understanding of the problem and what is not a reasonable approach has been concluded.

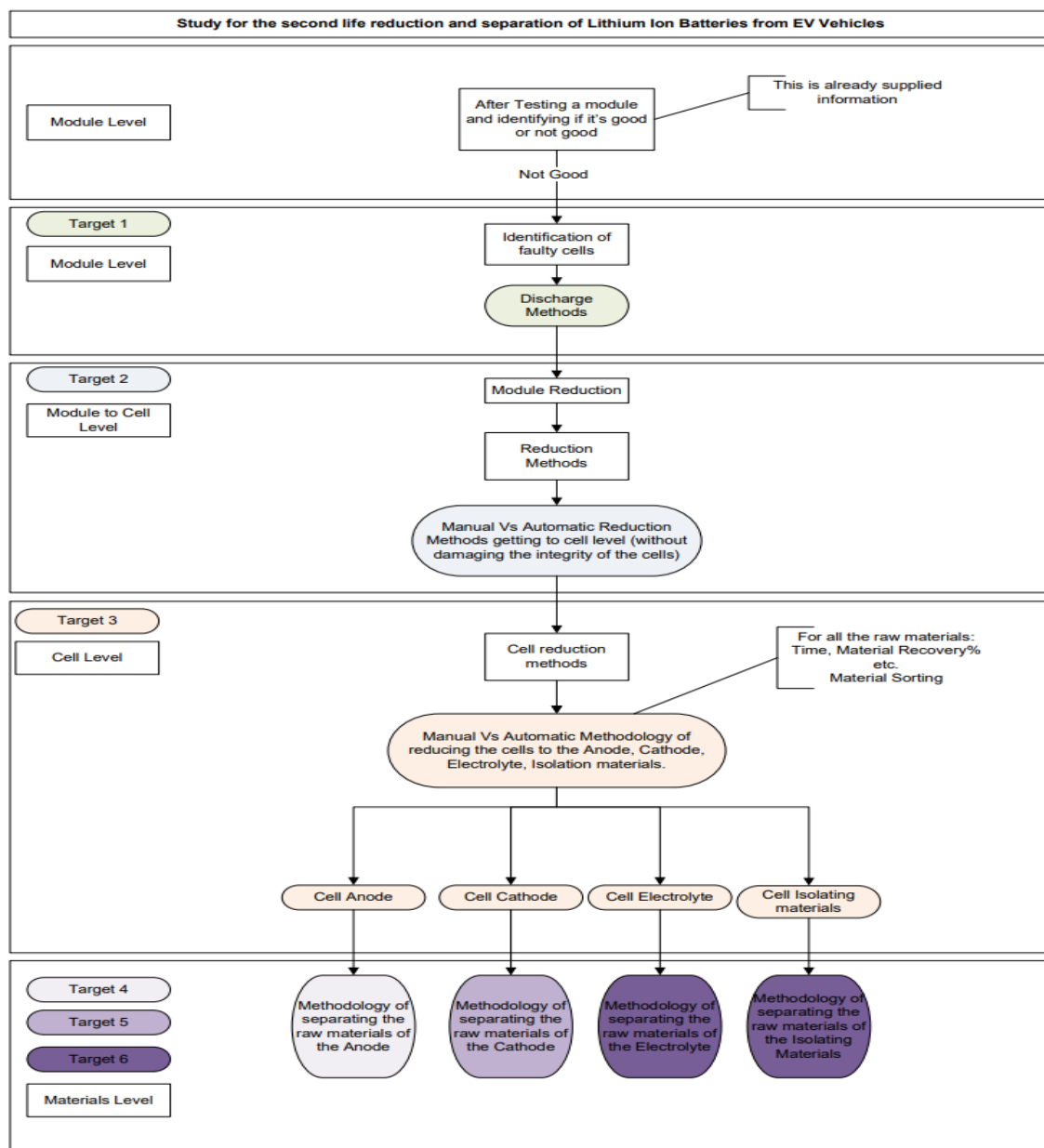
2 Introduction

To fully investigate the feasibility and all the necessary considerations to reduce lithium ion batteries to their constituent parts. The focus will be on the LG module fitted to the I-pace and the Samsung module fitted to Land rovers. Where possible any physical tests will be conducted with and aim to unwrap a cell.

2.1 Aims

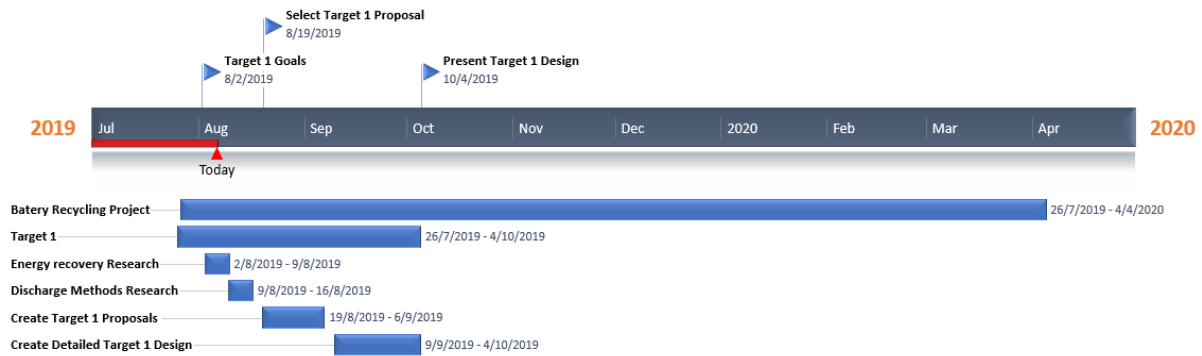
The initial project outline was provided by Treharne.

2.2 Objectives



3 Project Plan

The project was planned for major review at the completion of initial research and planning task 1 in October which redirected the project.



4 Literature Review

4.1 Second Life and Recycling

Currently the in-use lifespan of a lithium ion battery pack is 6-to 10 years (The Faraday Institution, 2018). Since 2009, in the UK, this would leave over 100,000 vehicles (Society of Motor Manufacturers and Traders, 2019) needing to replace their batteries. Although this lifespan is disputable, as the technology is both changing rapidly and varying widely between cell manufacturers' chosen chemical composition (Gandoman *et al.*, 2019), this still presents the automotive sector with a large amount of electrical vehicle (EV) waste that it has not encountered before. The traditional lead acid battery has strict design specifications for safety which also allow 99% separation and recycling of its parts. The lead acid battery was not the main energy store of the internal combustion engine (ICE) vehicle, but the battery electric vehicle (BEV) uses a lithium cell battery (LiB) which, at best, has an energy density of $0.9252 \text{ MJ kg}^{-1}$ (LG Industries, 2017) (although battery packs have at best $0.5368 \text{ MJ kg}^{-1}$ (LG Industries, 2017)). The modern BEV is competing with gasoline and diesel which have energy densities of around 45 MJ kg^{-1} . In the race to catch up with ICE vehicle popularity the recycling legislation has not kept pace and the only manufacturing requirements for lithium battery packs are for safety and repeatable reliability, as set out in UN 38.3. The modern vehicle LiB is often deemed to be not fit for current use when it only has 70% (Van den Bossche *et al.*, 2006) 80% (Tong, 2013) of its original capacity (Marques, 2019), but as the vehicle battery is of a high energy density and stronger separator construction for lithium ion compared to standard home electronics (Tong, 2013) there is potential for second life if its "state of health" can be quantified (Chang, Fang and Zhang, 2017). This has created a generation of vehicles that have no set way of repurposing the batteries' cells or recycling them to their constituent materials. Currently less than 5% of LiBs are recycled worldwide even though laws such as EU directive 2006/66/CE have set a target of 50 per cent (Cognet *et al.*, 2019).

4.2 Open Loop Recycling

Open loop recycling is a process where private companies recycle all the valuable materials within a product opposed to consigning them to incineration or landfill. Two main factors contribute to this process being undertaken:

1. The value of the recycled resource,
2. Legislation forcing the end user to pay for disposal at end of life

(Huysman *et al.*, 2015).

Therefore, if the value of materials drops, or it becomes too expensive for the end user to recycle a breakdown of the open loop recycling process occurs.

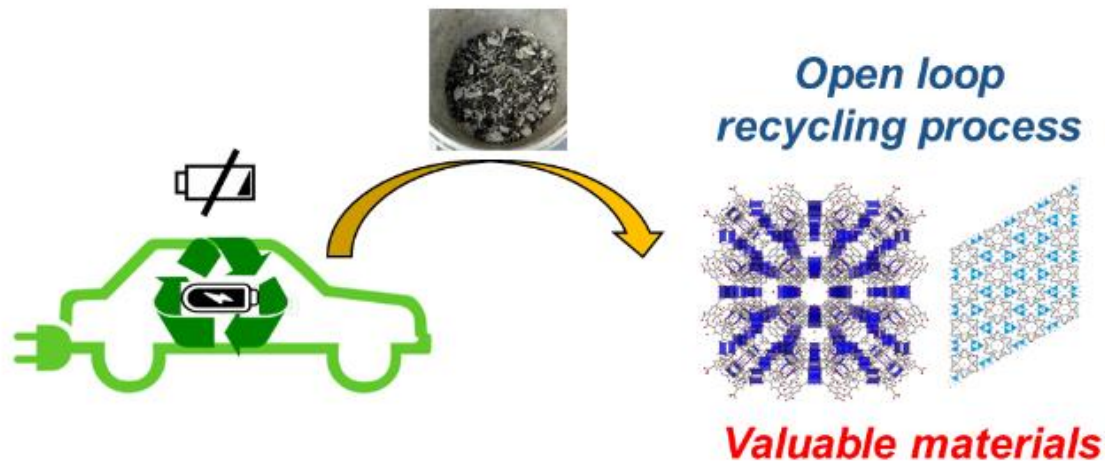


Figure 1 open loop process (Cognet *et al.*, 2019)

4.3 Closed Loop Recycling

This is when the manufacturer has a system in place where the onus is upon them to recover the product at the end of its originally useful life. In a closed loop system the recycling cost is built into the original sale cost. Closed loop recycling is either voluntary as part of a company's ethics drive or enforced through legislation (Huysman *et al.*, 2015). Currently there is no legislation forcing car or battery manufacturers to have a closed loop process in the UK.

5 Initial Test plan

Research had led to many unknowns in the ability to safely handle NMC cells with Treharne believing that there is no danger when penetrating or shorting cells.

As can be seen above similar NMC Cells present fire and gas dangers the LG MSDS sheet warns of risk of explosion risk of hydrogen fluoride gas release risk of fire.

To assess the Cells the following tests were planned to gauge dangers at different state of charges.

5.1.1 Plan to test module safe SoC

5.2 Testing lithium ion cells and modules energy release for safe strip down containment

Handling the modules in the project presents a safety risk. The following experiments are to give a better understanding of cell state of charge, health and risks when handling them at different levels.



Figure 2 General lithium reactions (washington)

During a venting reaction (i.e., no ignition of the vented products), the products consist primarily of electrolyte constituents. For most batteries, the products typically consist of carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2) and hydrocarbons (C_xH_x). These gases are flammable and present fire and explosion risk. For the burning scenario, the electrolyte burns efficiently producing primarily carbon dioxide (CO_2) and water (H_2O) as the by-products. For most batteries, the products typically consist of CO_2 and water vapor. The burning reaction also tends to liberate the fluorine from the lithium salt (typically LiPF_6) dissolved in the electrolyte. The fluorine typically reacts with hydrogen to form hydrogen fluoride (HF). HF production is also proportional to the electrical energy stored in the cell/battery and can result in dangerous concentrations. HF reacts with the water vapor produced during the reaction and/or with the mucus membranes in the human body (i.e., eyes, nose, throat, lungs) and becomes hydrofluoric acid (washington).

5.2.1 Pre experiment

Test different cells and modules state of health to find a range for the experiment.

- The state of health could increase or decrease the exothermic reaction if plating or dendrite has occurred that increases the surface area for the reaction in the electrolyte.
- Changes in the electrolyte composition becoming more unstable.
- A larger SEI could be stable.

5.2.1.1 SOC

Whilst a cell is under high load its voltage is lower than when it's unloaded. This presents a challenge when using voltage to predict the soc. To obtain a known voltage to use as a stopping point when discharging, the modules will need to be cycled at different c rates from fully charged to 75% DoD whilst counting the coulombs whilst monitoring cell temperature. This will show the accurate voltage at a SoC whilst under a set load. As individual cells can be monitored easily on the LG modules from the 12pin connector, but a can-bus interface will be needed to monitor the Samsung cells within its modules. If the cells are discharged at a slow rate and high temperature this can change the electrolyte if they don't have certain additives making them useless.

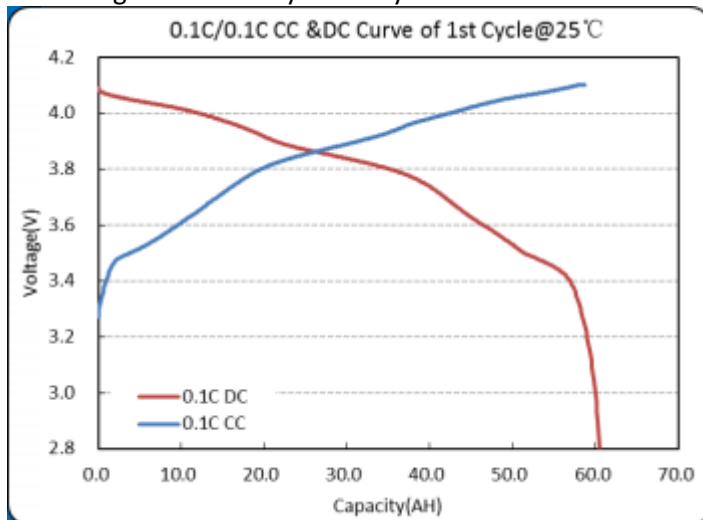


Figure 2 Ricardo Cell Analysis Report

Put different cells and modules at different states of charge;

- Fully charge the cells then discharge at set c rate monitoring voltage and counting coulombs to check DoD.
- Repeat at different C Rates to see the different voltage at known loads during discharge.
- Start test from different known SoC to lower SoC monitoring temperature as if working with partially discharged modules.
- Repeat tests for modules using 12pin connector on LG and CAN-BUS on Samsung to monitor the cells and overall module voltage.

5.2.1.2 SAFE HANDLING OF MODULES

The lithium ion modules for recycling potentially contain allot of energy which if not handled correctly present dangers. From research lowering the SoC of the modules reduces the risk of thermal runaway when pierced or shorted. TIAX nail penetration study shows the reduction SoC reduces the thermal event.



Figure 1 TIAX Nail Penetration Test (IATA, 2019).

This test was carried out on 18650 2.6 Ah NCM and LCO cylinder cells. Further tests would need to be carried out on the Samsung prismatic cells and LG pouch cells at low states of charge as these are 37 and 58 Ah cells and at lower SoC they still may have a significant thermal event if punctured or shorted.

The IATA limits the SoC of lithium batteries to 30% for flight transport (IATA, 2019).

If an entire module is shorted in strip down at an average 30% SoC some of the cells may have significantly higher states of charge as the modules in question are faulty. Shorting multiple cells presents the risk of a higher exothermic reaction as the event scales up.

5.2.2 PROPSAL FOR SAFE HANDLING SOC

- Further tests on shorting the cells in this project at lower SoCs to see if the reaction is at an acceptable level.
- Tests on shorting a module at a lower SoC to see the effect on scaling up the reaction.
- Penetration tests on cells and modules at different SoC.
- Measure the heat release with thermal camera (from university)
- Record the speed of reaction with a high speed camera (from university)



Figure 3 university high speed and thermal cameras

Maximum heat released K Table of results

State of Health		State of Charge								
		25	30	40	50	60	70	80	90	100
	50	x								x
	60		x		x		x	x	x	
	70			x		x				
	80				x		x	x		
	90		x	x		x			x	
	100	x								x

Speed of reaction Table of results

State of Health		State of Charge								
		25	30	40	50	60	70	80	90	100
	50	x								x
	60		x		x		x	x	x	
	70			x		x				
	80				x		x	x		
	90		x	x		x			x	
	100	x								x

As long as the maximum and minimum results are obtained (corners of table) and a spread across the rest of the table matlab can be used to interpolate other results.

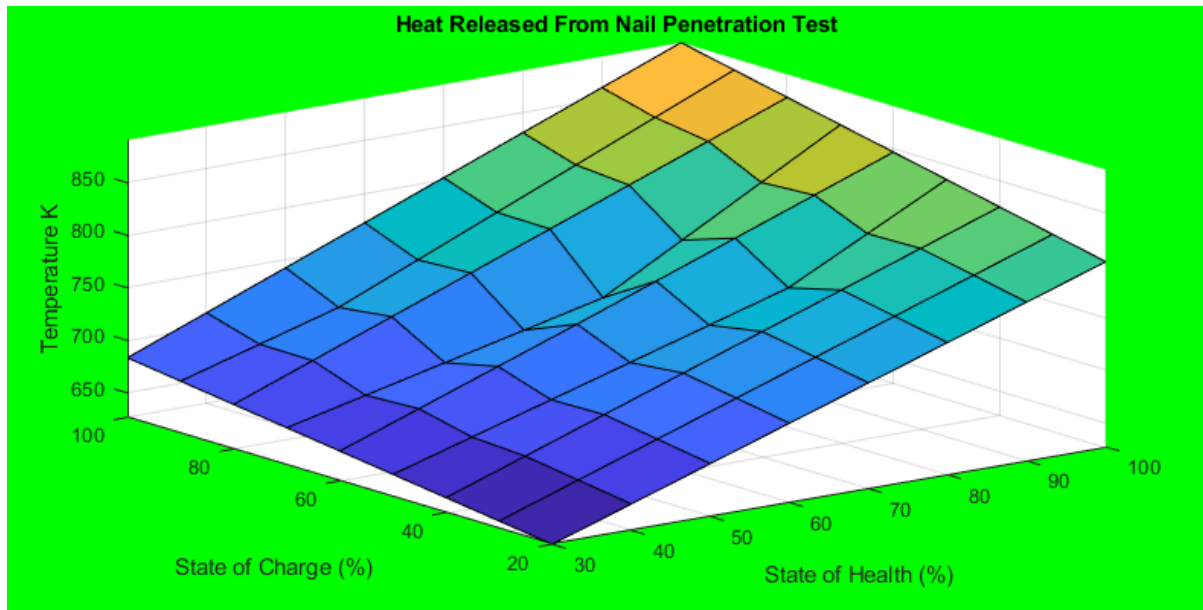


Figure 4 Example of results

5.2.3 Risks

The shorting and nail penetration tests should be carried out remotely. A previously made drop test rig can be adapted to use for a nail penetration test.



5.2.4 PPE

- The tests need to be carried out in a well ventilated area with a safe place to evacuate to.
- Class D powder fire extinguisher for combustible metals. (Fire Champion Lith Ex Lithium Ion Fire Extinguisher claims to be a specialist extinguisher only up to 60Wh)
- Welder's jacket and apron.
- 3M 9906 Particulate Dust Mist and Nuisance Hydrogen Fluoride HF FFP1 Respirator
- Full face shield.

5.2.5 Possible collaborators

5.2.5.1 Radnor

University already collaborates with them on ballistics projects and they test energy release from explosives.

5.2.5.2 Fire service

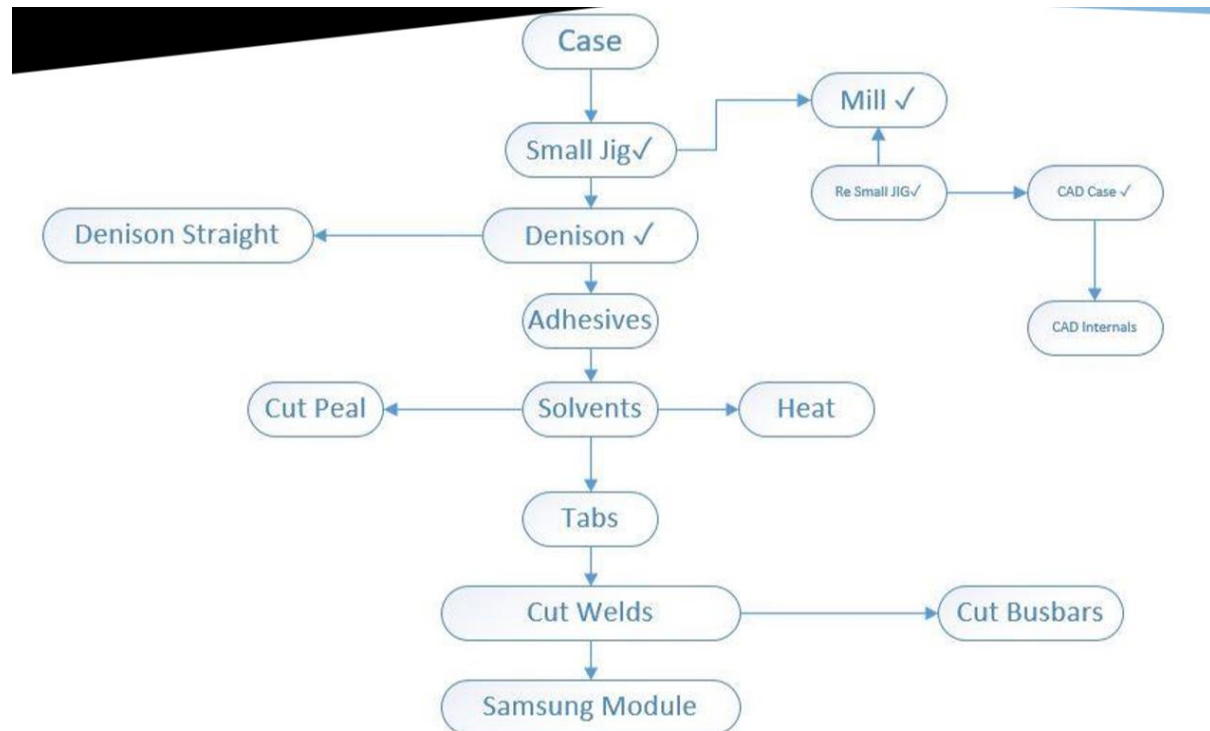
South wales fire service may provide a test location if they need training with extinguishing high energy EV batteries.

Make sure that calcium gluconate gel is available in the first aid kit.

Please see the appendix for risk assessments and safe practices for the tests.

6 New Direction

As there was no available location at either Treharne or the university or willingness to carry out the said tests the following plan was proposed.



This is where most of the work would be focused on removing the LG module Casing.

7 Discharge Test

7.1 Objective

To reduce the energy within the module and therefore reduce the danger from accidental thermal runaway.

7.2 Problem Detail

To drain the module to allow safe (although this has not been proven to be a safe state) future reduction to cell and pouch level the method chosen was total loss to resistors because it was easy to set up and the facilities had already been provided by Treharne so there was no cost incurred.

This type of drain test is of little value when assessing the module condition or the point at which damage may occur due to voltage drop. The test, to check when damage may occur due to the drop in voltage not maintaining enough electrical potential to prevent plating and dendrite, is performed at constant current at a set temperature.

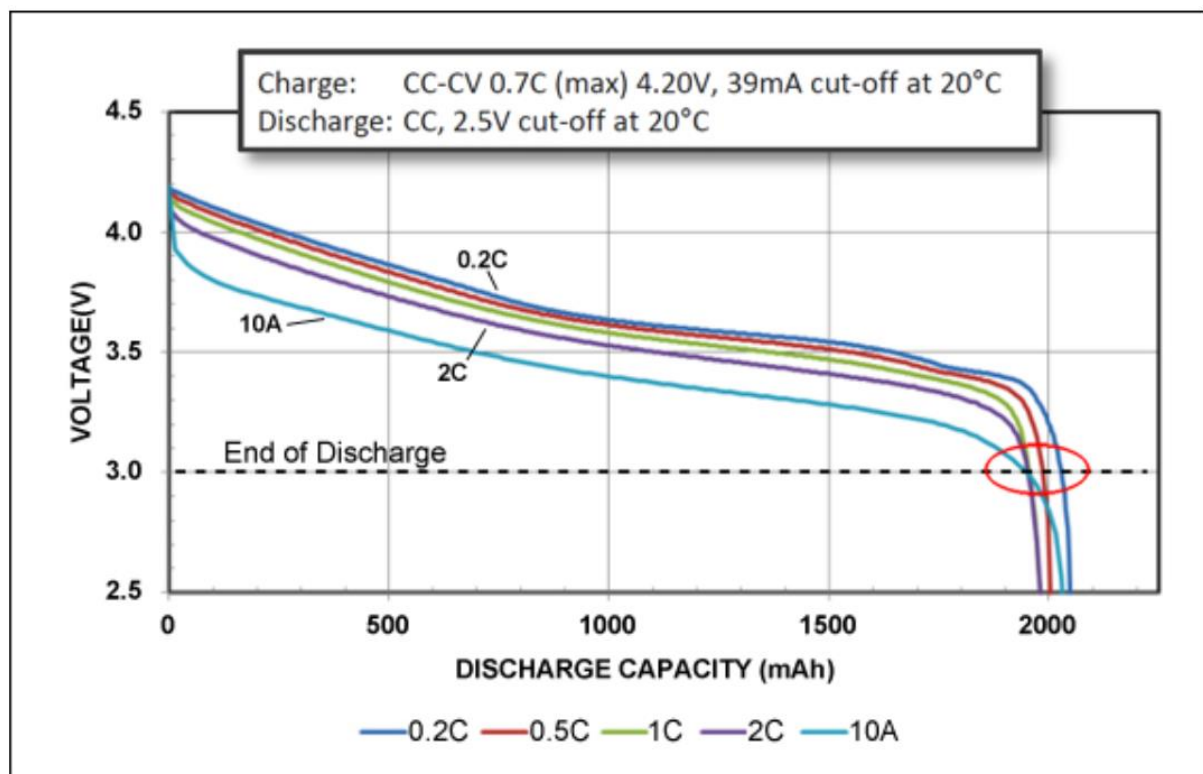


Figure 5 Typical Constant Graph (Viswanathan, Palaniswamy and Leelavinodhan, 2019)

As can be seen in the above graph there is a knee point which depends on the C rate at which the battery is drained throughout testing where the capacity 2C crosses 5C (shown as 10A as the cells were 2Ah) has been taken as the end of discharge (Viswanathan, Palaniswamy and Leelavinodhan, 2019). This test was performed on the NMC cells but the proportions of nickel, manganese and cobalt were equal, whereas the LG cells in question have NMC ratio of 3:1:1. The cells tested at constant current in the study were 2 amp hour (Ah) whereas the LG are 58 Ah and the polymer separators and organic electrolytes are unknown so their 5C to 2C crossover cannot be taken as the safe limit and therefore a higher limit of when the knee point first occurs must be assumed.

This test poses an additional problem: the module needs to be drained to reduce the risk of thermal runaway when it is broken down. As the module has 12 cells in a configuration of 3s 4p this gives it a:

$$total\ Ah = Cell\ Ah \times no.\ in\ series$$

It has 232 Ah Capacity or a 1C discharge rate of 232 Amps. With a nominal voltage of 10.8 this would require a resistance of:

$$R = \frac{V}{I}$$

0.046 ohms across the module. This was not achievable with the equipment available from the university or Treharne. The complete pack of 36 modules in series (giving a pack of 108s 4p thus making the C rating of the module the C rating of the pack as current increases with more parallel configuration) is rated to a continuous power of 110KW with a pack voltage of:

$$total\ V = Cell\ V \times no.\ Cells\ in\ Series$$

338.8 Volts (nominal 3.6 volts) or 453.6 volts (maximum 4.2 volts). This will give a cell draw of:

$$I = \frac{\frac{P}{V}}{no\ cells\ in\ parallel}$$

81 amps nominal or 1.3C discharge rate and 60 amps max voltage or 1.03C discharge rate. This can be achieved in use as the voltage is increased meaning at the same current you have more resistance due to ohms law. Giving a constant resistance:

$$R = \frac{V^2}{P}$$

1.9 ohms max voltage and 1.0435 ohms nominal. The battery can deliver 321kW of instantaneous power at max voltage which is a resistive load of 0.64 amps or a current draw of 708 amps or an instantaneous discharge of 3C. All of these are realistic on a vehicle as continuous or instant figures, but to get 0.046 ohms on a module would be difficult due to the small terminals as resistance is inversely proportional to its cross sectional area and the distance of the terminals at over 360mm increases resistance as can be seen in:

$$R = \rho \frac{l}{A}$$

The lowest safe achievable resistance is 0.3ohms. This is from 4 1ohm resistors in parallel and thick gauge cable. Lower resistance could be achieved with just thick gauge cable or thick busbar, but this would generate excessive heat, further lowering resistance, as the energy increases the difficulty for electron flow and creating a fire risk as the cable heats up conducting heat into the module.

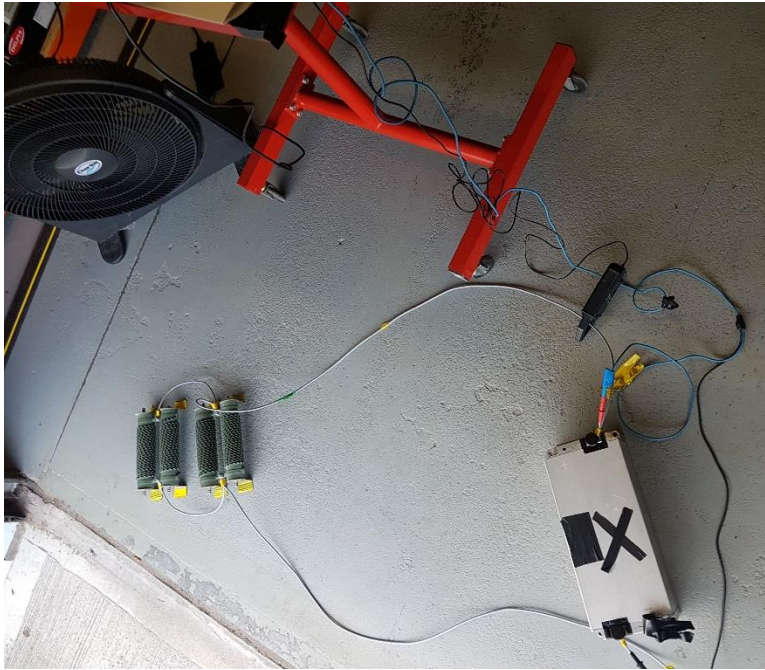
As this set up would produce constant resistance (although this will change throughout the test slightly with the increase in resistor temperature initially, then a fall of resistor temperature as the power reduces due to the module voltage lowering) but inconsistent current the results would not be comparable for voltage drop against capacity due to the fact the voltage and current will be both dropping simultaneously.

7.3 Method

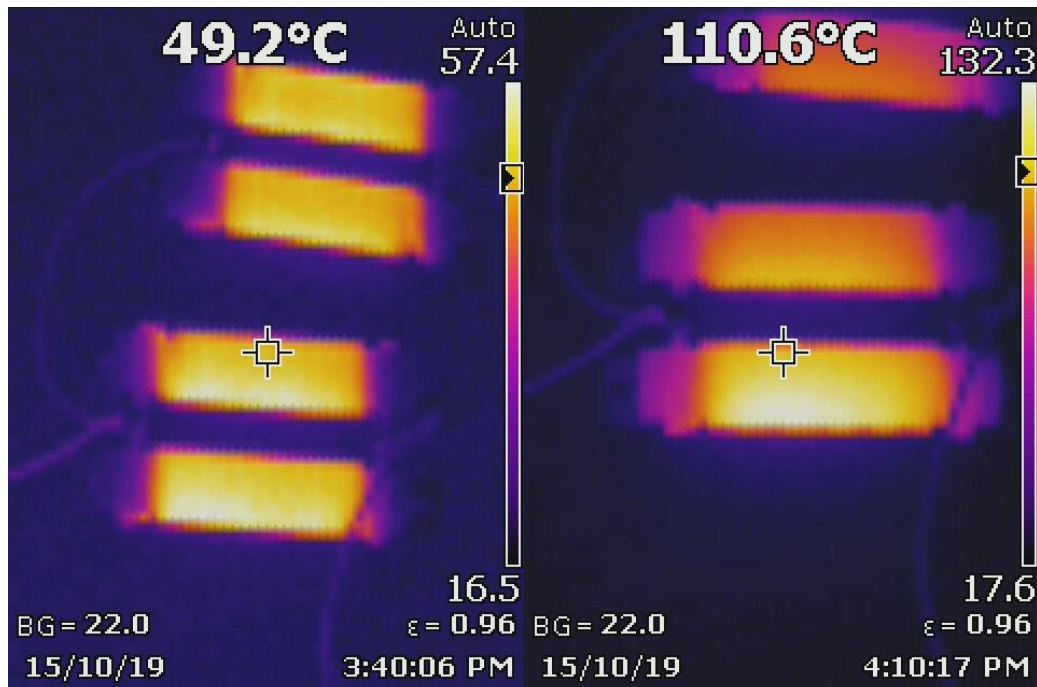
4 1 ohm resistors will be joined in parallel drawing approximately 40 amps (the starting voltage is close to 12) this will give a minimum test time of 5.8 hours (as the C rate is 232Ah) but this will be considerably longer as the current drops with voltage.

Safety precautions for working with modules can be found in the appendix.

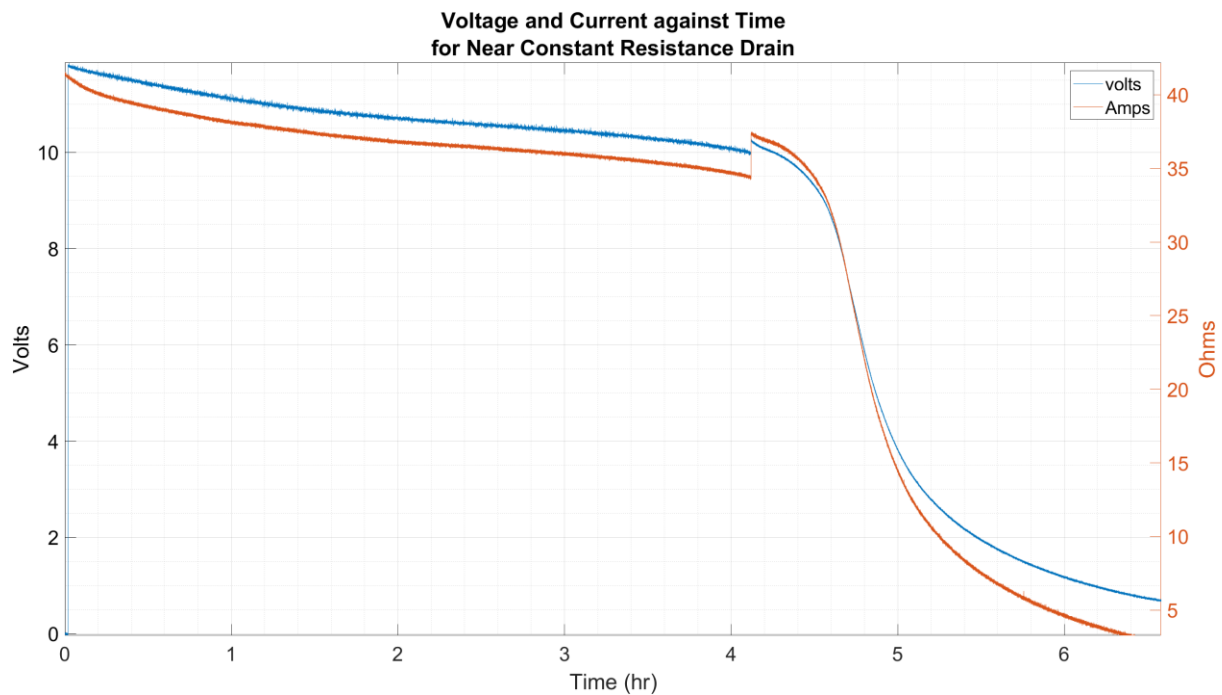
A fan was positioned to cool the resistors to stop them burning out and to help reduce the resistance of them.



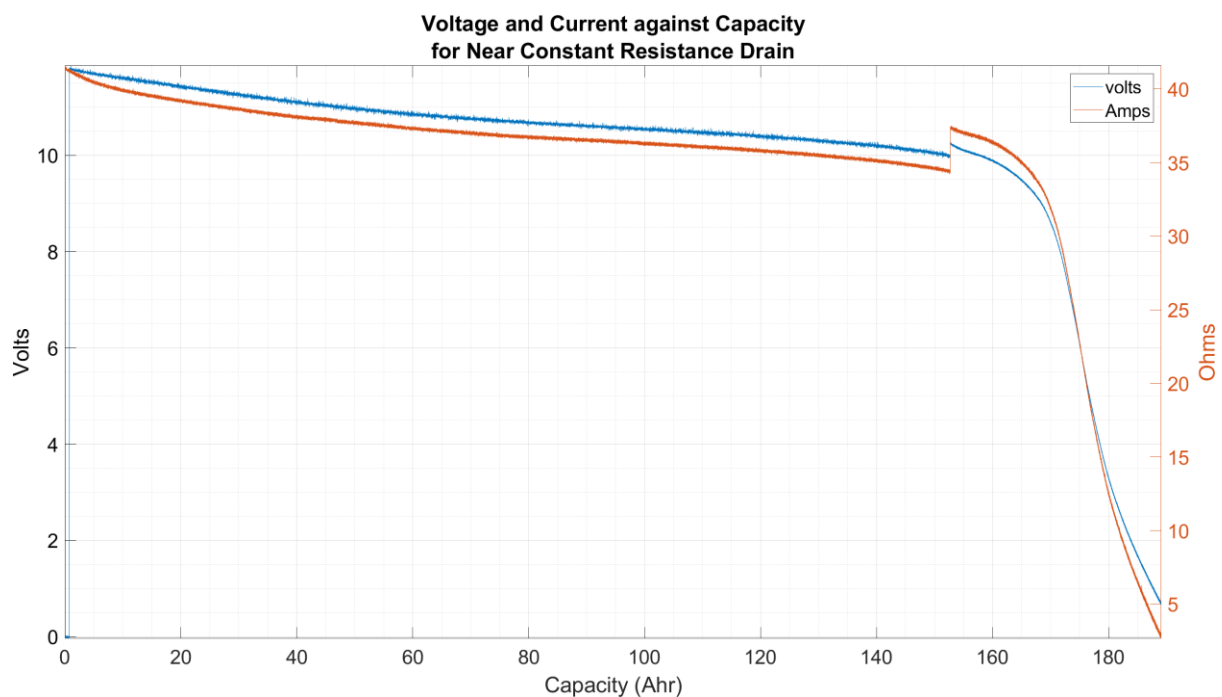
The voltage and current draw were logged on a picoscope. The current sensing method was with the pico amp clamp this is an inductive hall effect current sensing device. This is not as accurate as a shunt resistor and as the resistance of the set up would vary with temperature this was seen to be the best method.



The previous figure shows the temperature of the resistors towards the end of the test and at the beginning. This shows that the test was neither constant current nor constant resistance.

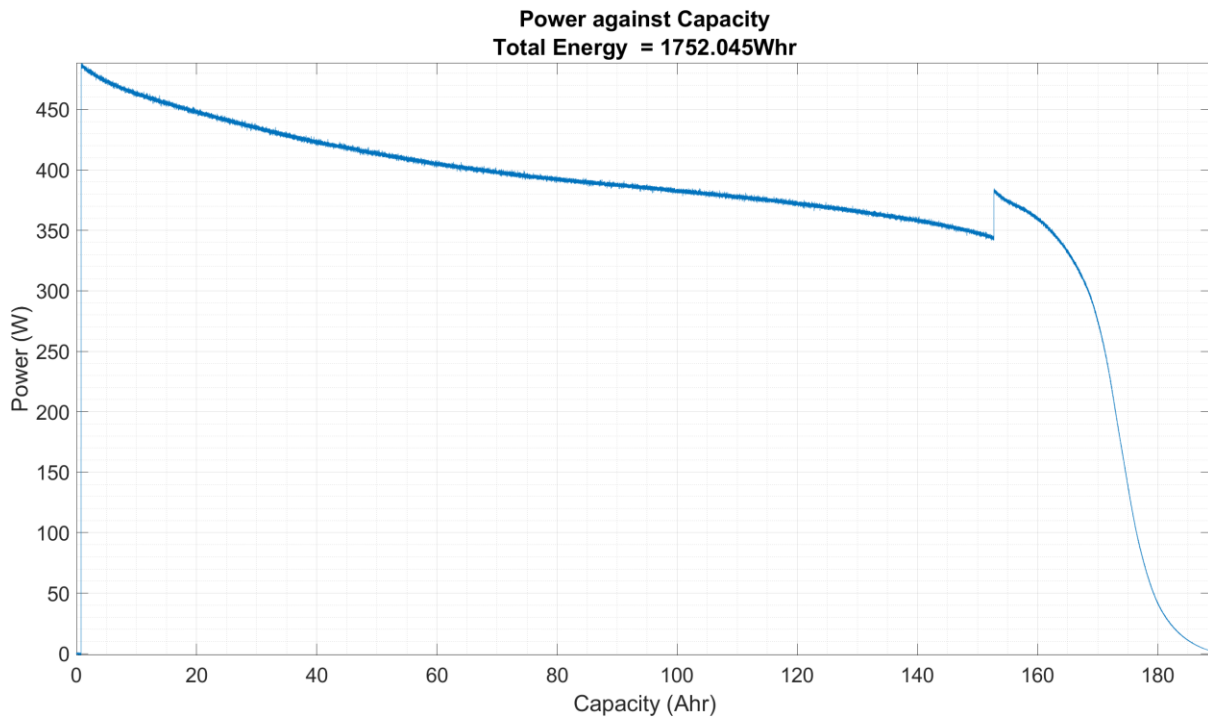


The graph above shows the data logged from the tests the jump after 4 hours was due to the fact the test was performed over 2 days and there was slight voltage recovery as the load was removed. The second day was colder so the air from the fans reduced the resistance increasing the current showing a higher current for the same voltage.



The graph above shows the voltage and current draw against capacity this does show a more pronounced knee point, but this would be greater if the current level was

maintained. The total capacity drained is considerably lower than the total capacity this is due to the module not being at full charge and partly Peukerts law which states that the higher the current draw the less recoverable energy due to losses in heat generation and higher resistance. The amp hours were calculated from the cumulative current for the time step in hours.

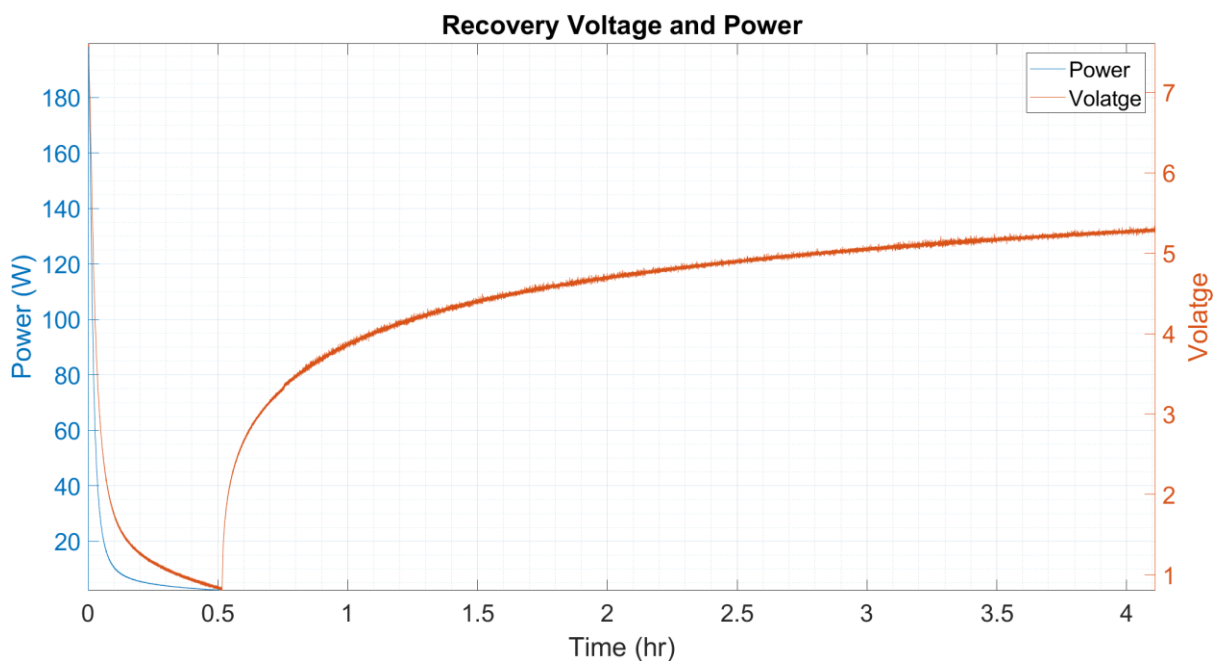


The above graph shows the power output against capacity as expected this follows the previous trends with the power dropping faster than the voltage in the beginning due to the increasing resistance and lowering current. The energy removed by the resistors was 1.75KWh which is less than the total energy of the module, but it was not fully charged. To calculate the energy usually the nominal voltage is multiplied by the total capacity. As the voltage range is so large in this test the change in voltage per unit capacity was multiplied and summed.

$$E = \Sigma((V2 - V1) \times Capacity)$$

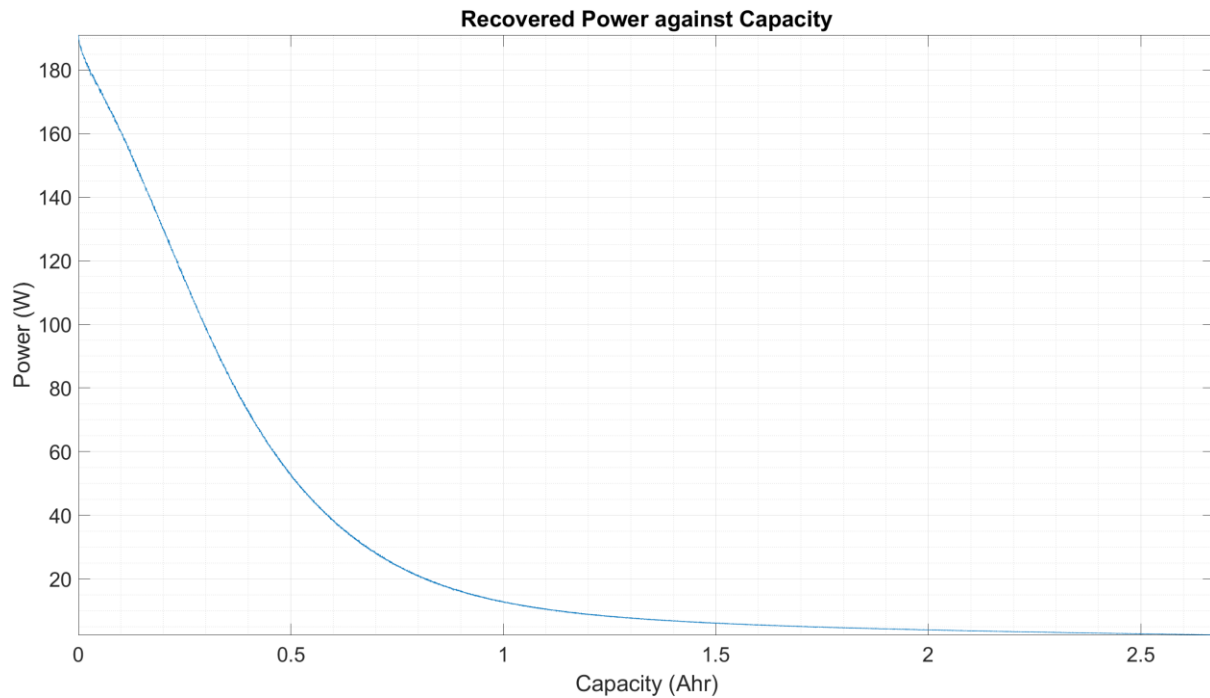
8 Module Recovery

After the modules were taken to below 1 volt in the previous drain tests once left, they returned to over 7 volts. The modules were then re drained then monitored as the voltage increased. The same 4 1-ohm parallel configuration with the Pico scope was used. The current was not monitored as the resistance barely changed in the external circuit and ohms law was used to calculate the current and power. there was only voltage to measure during the recovery as the resistors were removed when the voltage dropped below 0.9 volts.

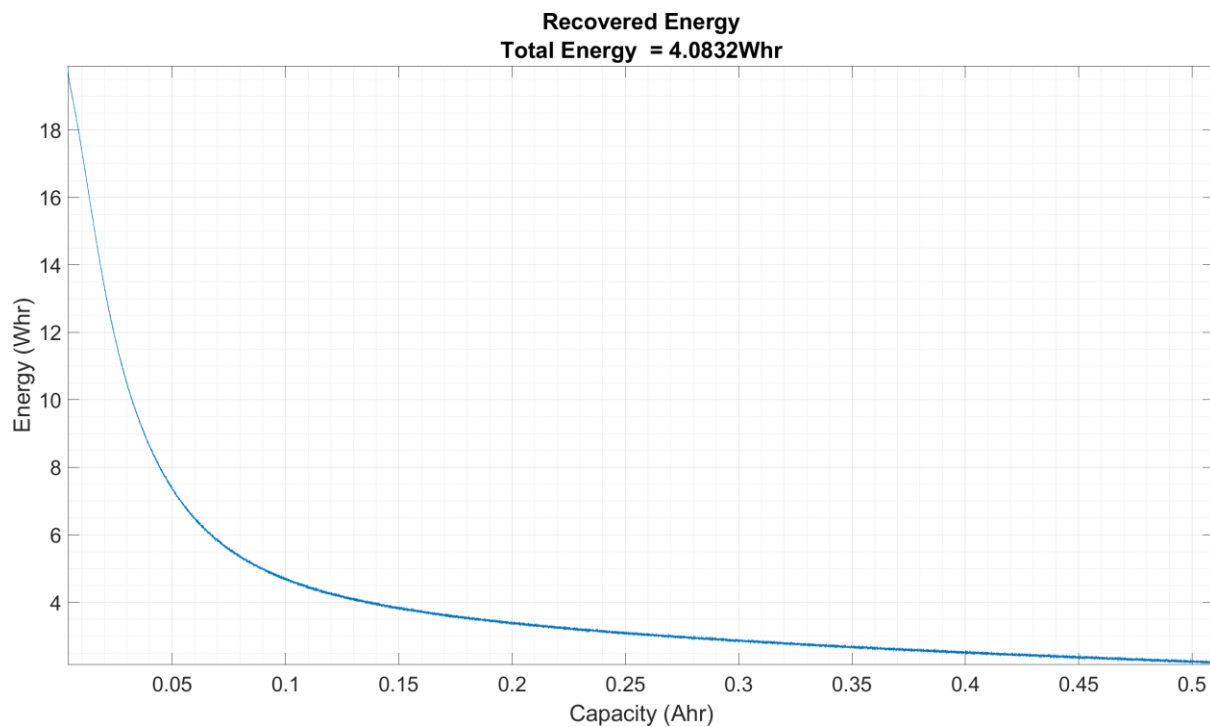


This had enough current and instantaneous power to blow a 30-amp fuse, but the total energy was very low. After the test had been stopped the voltage kept rising until it was over 7 volts the next day. The electrochemical properties of the collector plates and the electrolyte anode and cathode have potential in an uncharged state. This uncharged potential is checked as part of the manufacturing process with manufactures failing cells that are bellow a threshold pre charge. This threshold varies depending on cell chemistry between 1.8 and 2.4 volts. As the module has 3 in series the initial voltage of 7.45volts gives a cell voltage of 2.48 volts and as these are high capacity cells and it was not possible to fully drain due to the resistance of a wire this could be the cells returning to that state. The initial steep recovery in voltage after half an hour is due to the load being removed. The high kick up when the load is removed is due to the electrons normalising which at a lower capacity has a greater effect, they are all pulled to the

anode current collector by the resistors but the current draw isn't great due to the low voltage then when the load is removed they shift back through the cell.



The previous graph shows the power output is short lived and the capacity is only around 2.6 ah. This is to be expected as the



The previous graph shows the total energy is only 4whr and with the varying voltage shows that there is no use in this energy.

9 Casing Removal

The aluminium case is made of an extruded centre tube with a cast aluminium end cap welded onto each end. Represented by items 7, 5-1 and 6-1 in the following image.

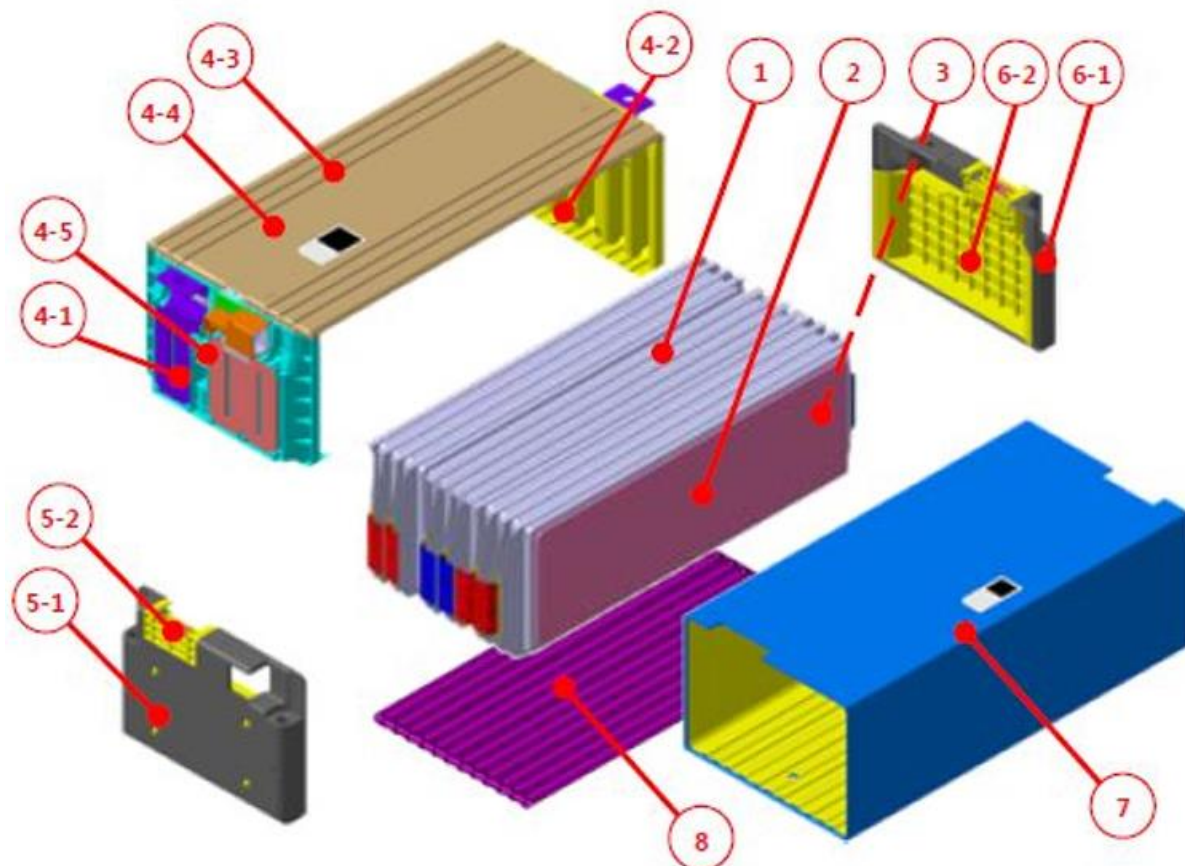
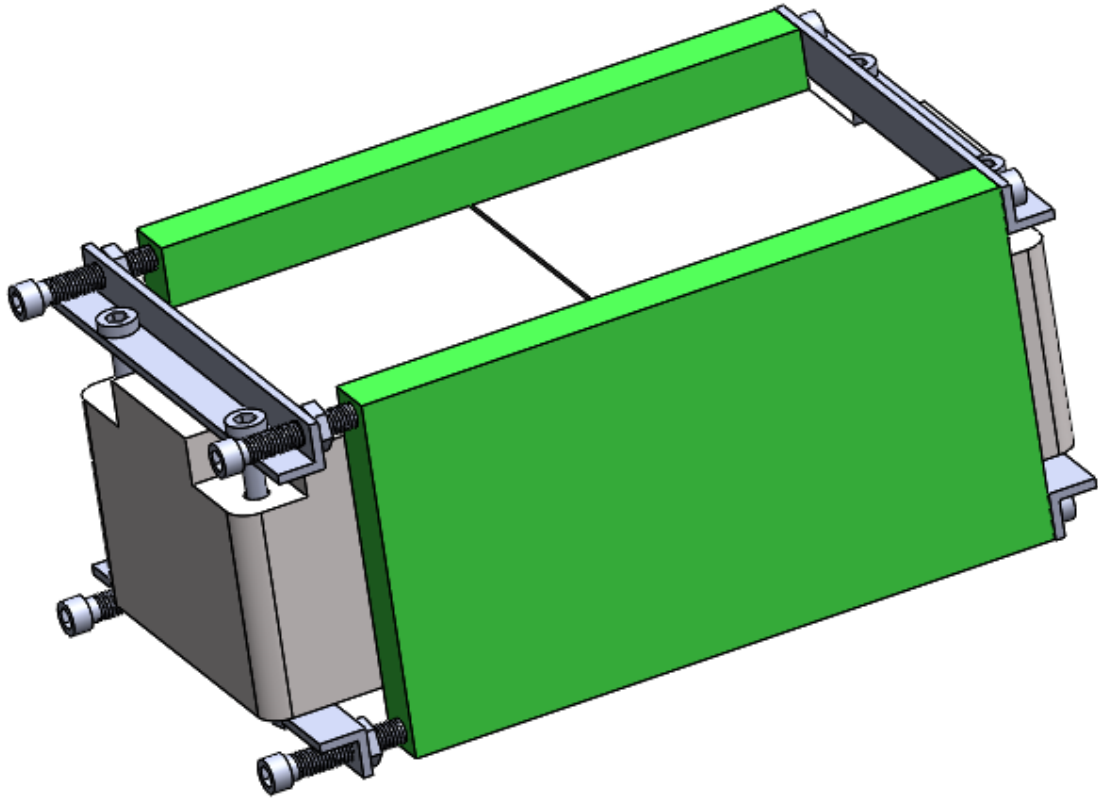
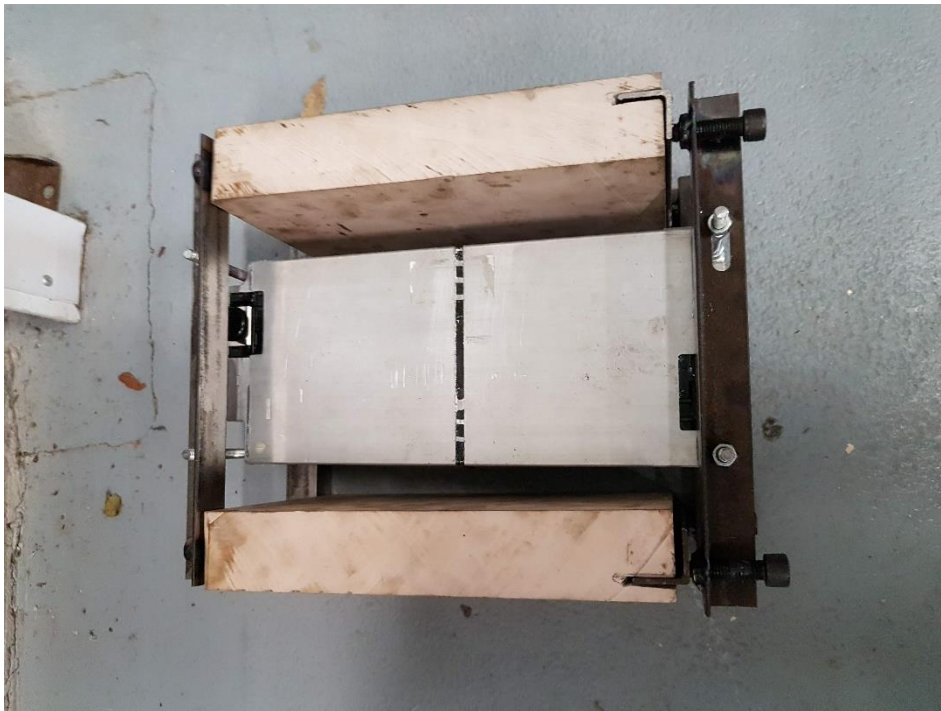


Figure 6 Exploded view (Chemicals, 2018)

When manufactured the cells are slid into the tube. As the cells are inserted using a clamp and then swell in use, they will be very tight inside the tube which is visually bowing. The first concept was to split the module around the centre. And pull the two halves apart. As one half removes this allows the cell swelling to move to the outside half of the cells allowing for easy removal.



The above illustration shows the module scored around its centre in a rudimentary prototype puller to attempt this concept. This did not work as the puller buckled and the base of the central tube part did not move.



The above image shows the gap appearing in the top of the module.

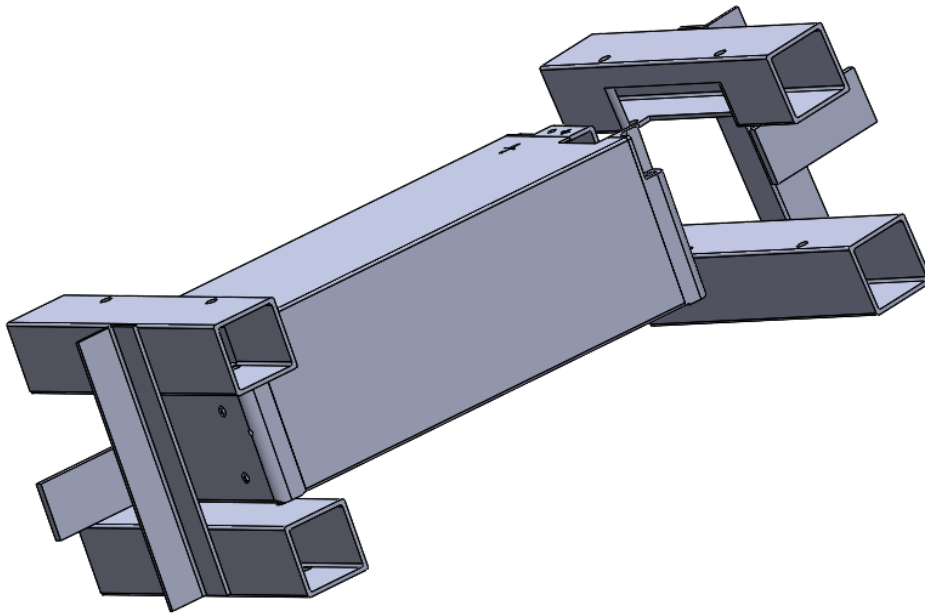


The above image shows how to remove half the casing the base had to stay in place and the sides and around the base had to be milled away. The base was stuck to the cells with thermal compound an attempt was made to scrape it away and this pierced the cell with little force.

Treharne requested that the strength of the case be tested and if the end cap welds could be easily broken to remove the end caps.

9.1 Breaking off the End Caps

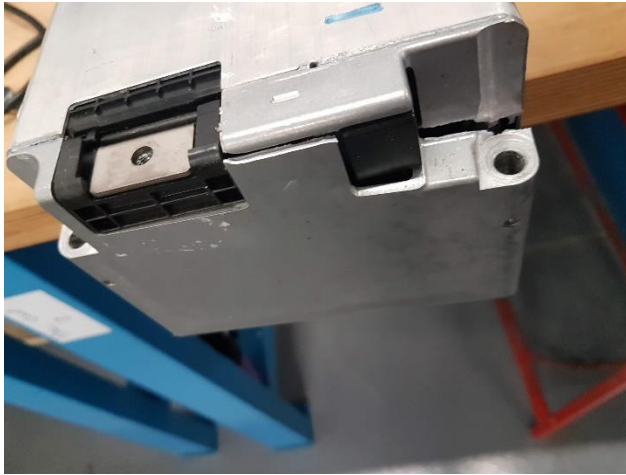
The first method to attempt a clean break of the module end caps was to secure a thicker steel jig to each end of the module through the cap bolt holes and pull apart with university Densison strain puller.



The above image shows the design for the 2 jigs to fit through the bolt holes and in the Denison jaws. The box section had to be cutaway to allow a snug fit as any gap would allow a bending moment on the bolts.

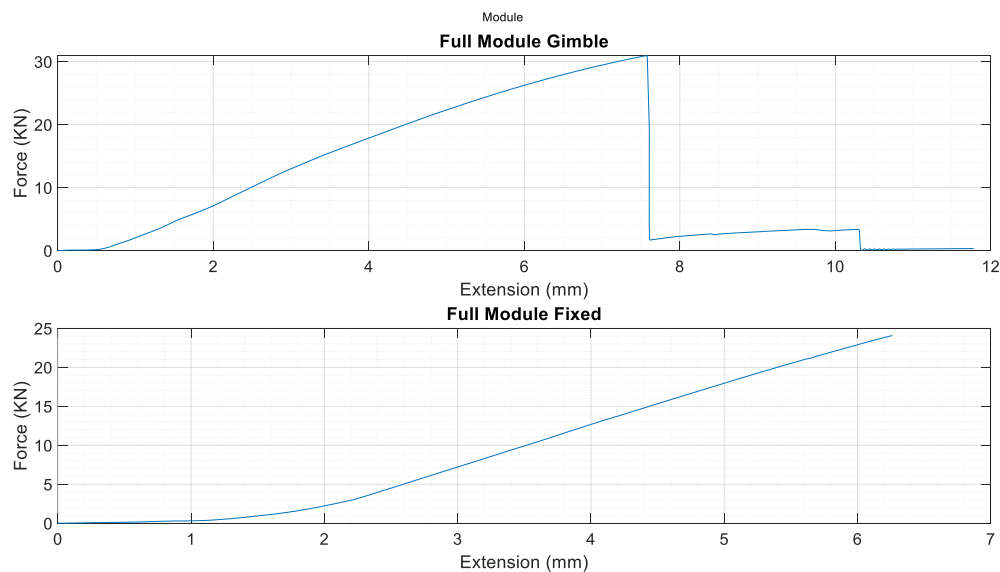


The above figure shows the module mounted within the Denison strain machine.



The tabs on the jigs that located in the Denison jaws were centralised for the end caps to give a square pull. The end cap broke on first instead of the welds then it tore on the welds. This was not the desired result as this would result in more machining to remove the section not attached to the bolt holes.

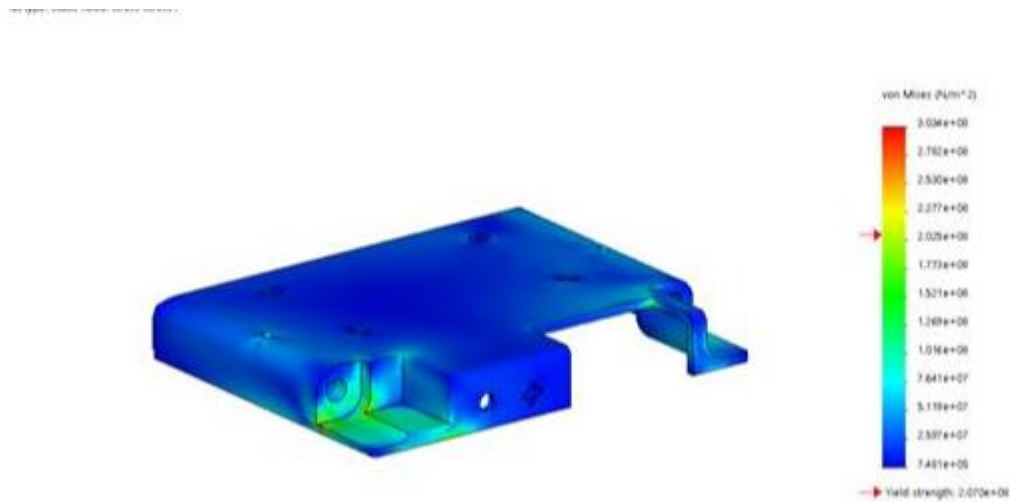
The Denison machine has a gimble at the top to allow it to pull the test piece in the weakest direction as it deforms. This may allow it to apply a moment to the end cap as it finds the weakest part. A thick steel tube was machined to stop any movement in the upper jaw. The test was repeated, and the end cap broke in the same position again.



The end cap cracked at 30 and 24kN in the two tests. This test was only used to see if the end cap could be broken off cleanly and at what force. As the module was not a uniform shape and there was extruded aluminium, cast aluminium and a steel jig the extension measured is meaningless.

9.2 Static FEA

A accurate cad model was created with material properties for typical extruded and cast aluminium added. A 1.6mm weld bead was added in CAD and a force was applied pulling on the CAD jig putting contact force through the module.



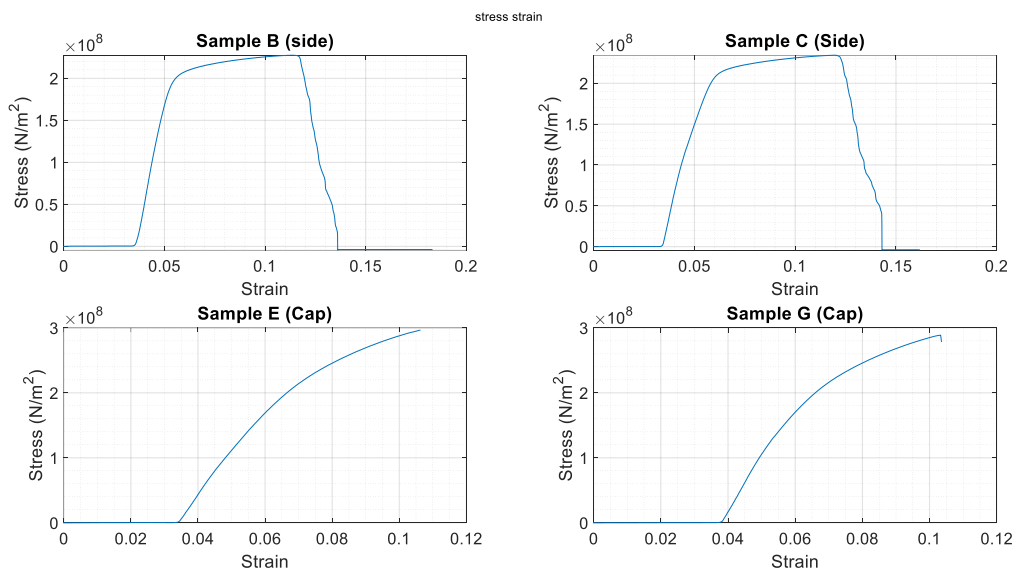
The above figure shows the FEA model had the stress concentrated at the position the cap cracked. This gives confidence if the cap was to be pulled by the bolt holes without weakening the weld of the section that remained it would crack in the same place again.

9.3 Material and weld strength

To automate any future module dismantling tests were performed to find the young's modulus and ultimate yield strength of the material. Ideally dog bone test pieces would be machined from the module parts, but due to the machine shop not being available strips were hand cut.



The above picture shows the test pieces some broke on the stress concentrations caused by the Jaws of the Denison machine.

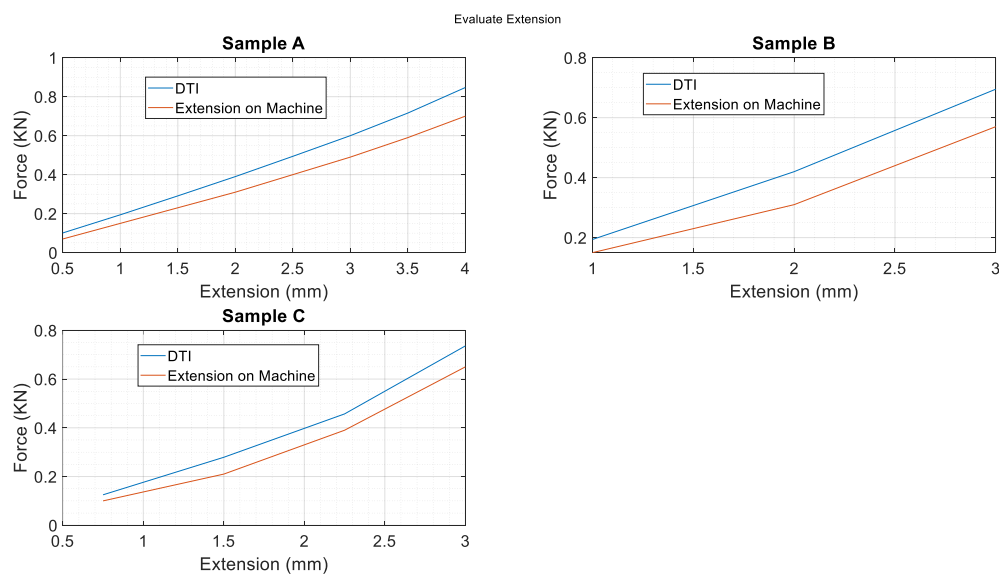


Above are the results for the test parts that didn't break on stress concentrations caused by the jaws.

When the researched range for aluminium's young's modulus was anything between 50 and 90 GPa. When calculating the values found were between 6 and 13Gpa. These results were outside the range, so a test was devised to check the Denison machine.



The above figure shows the DTI inserted to measure the extension to be compared with the machines read out. The machine was set to pull in 0.2 KN increments the extension was measured on the DTI and on the read out.



The above results show for the same force a greater extension was measure by the machine. This will increase the strain and as strain is inversely proportional to the young's modulus this is a definite cause of the low calculations. To evaluate the force

weights were placed on the bed table and the force went up accordingly but as the bed measured in KN and only 20kg were added giving 0.2kN increase this did not check the full range.

10 Break Down LG Thermal Resin with temperature Report

The standard operating temperature range that EV batteries vehicles are now manufactured to operate in are between -20C and +60C. if the batteries are military grade they must operate between -40C and +80C.

10.1 Objective

To break down the adhesion in the thermal resin and remove the cells from the aluminium base, without damaging any of the cells to allow for recycling and repurpose.

10.2 Problem Details

Although thermal resin will not breakdown within the working temperature range of the modules, the adhesion or modulus may relax, and the cells release as the resin is believed to be there for conduction and not attachment. The thermal resin is believed to be epoxy based thermoset adhesive. The product is made by LG chemicals and the closest match found for resale is from Appli-Tec. The solution is injected into the base of the module case (figure 1 item 7) and then sets after curing as a resin.

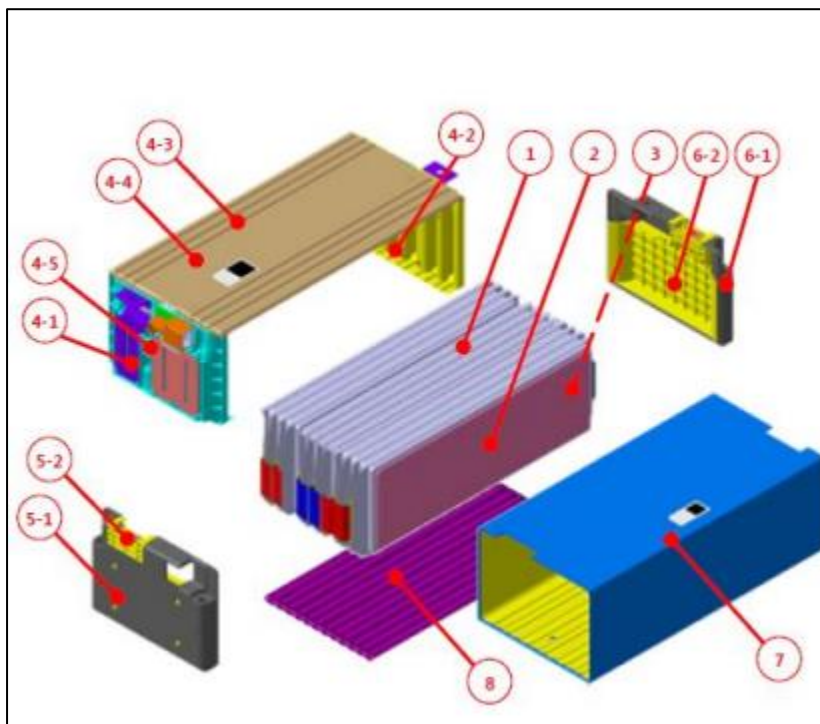


Figure 7 module construction breakdown (Chemicals, 2018)

Figure 1 shows the resin as a base layer (8) from inspection it appears to have been injected through holes at the base of the module and has risen to the top (or flowed down before setting upside-down) this poses additional problems as the resin is over a larger

more inaccessible area of between the pouches surfaces. This can be seen in the following image.



10.3 Reasons for Heat Exposure

The following graph (figure 3) shows the change in modulus of urethane resins through a change in temperature (Petrovic, 2018) from a Dow Chemical's study. The chemical make-up of the resins in the Dow study is different to those used by LG but this shows why applying heat may be beneficial.

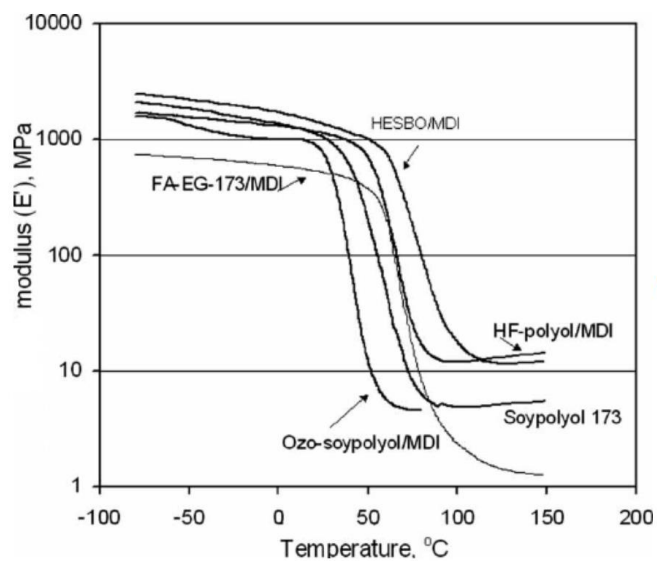


Figure 8 modulus change with temperature rise (Petrovic, 2018)

The original modules are believed to be baked to 80°C (Chamberlin,2020) to rase gases within the pouches to the top, therefore this temperature will be taken as a safe maximum temperature for the modules. Figure 4 shows that some epoxy resins have a drastic reduction in modulus above 50°C.

10.4 Reasons for cold Exposure

The adhesive bond between the resin and the surfaces it contacts may be reduce with exposure to cold temperatures which can be seen in the following graph from a study into adhesive technology ('Characteristics of Adhesive Materials', 2009)

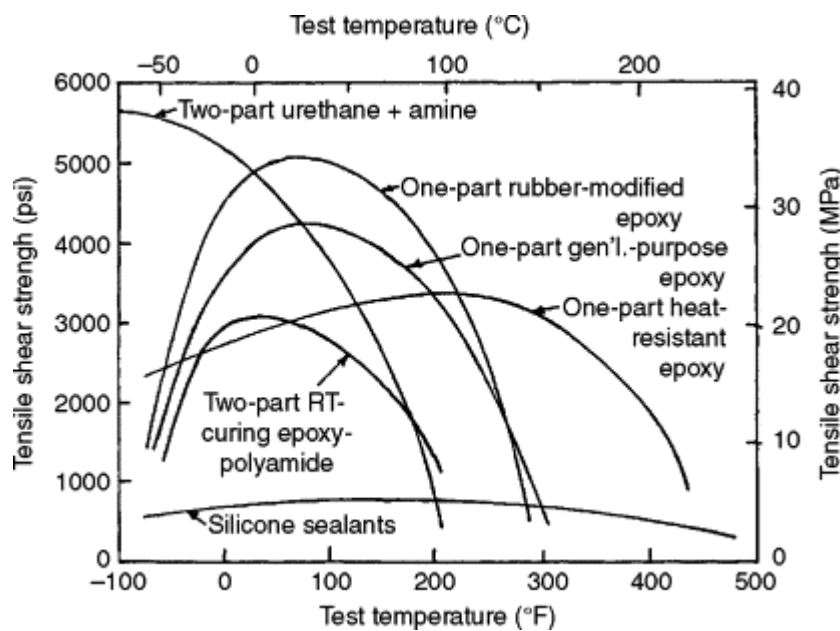


Figure 9 low temperature effect ('Characteristics of Adhesive Materials', 2009)

10.5 Tools and equipment PPE and Safety

Please see appendix on module safety handling

Temperature logger

Scales

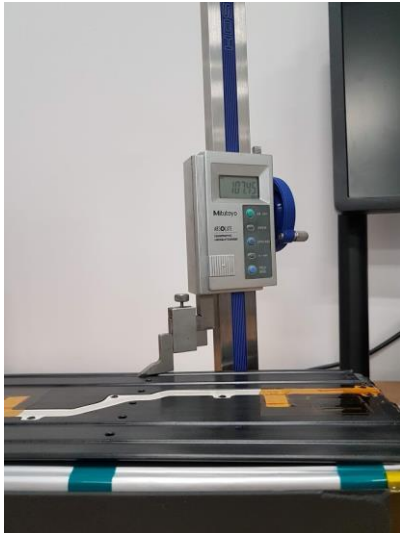
Vernier calliper

Jig was constructed to hold the module upside down.

10.6 Method

10.6.1 Pre test

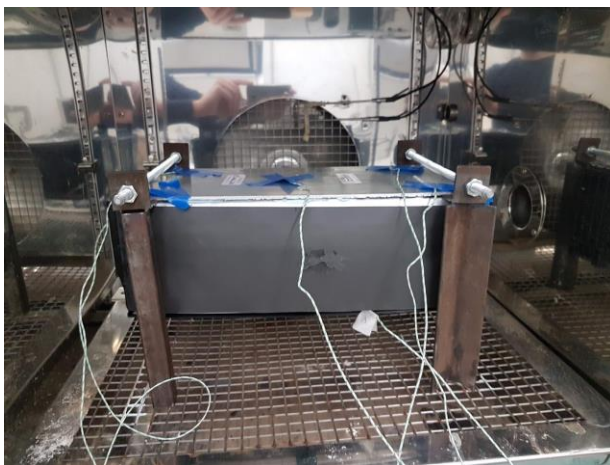
- Drain module with resistors (as previously described)
- Install wire to maintain dropped safe voltage (same as casing teardown)



- Measure outer dimensions of module (use digital height gauge and Vernier callipers)



- Weigh mass of module



- Create jig to suspend module by base



- Attach temperature Probes

10.7 During Temperature exposure



During the test, the temperature will be monitored and logged with the Pico TC-08



- The module will be observed during the hot test.

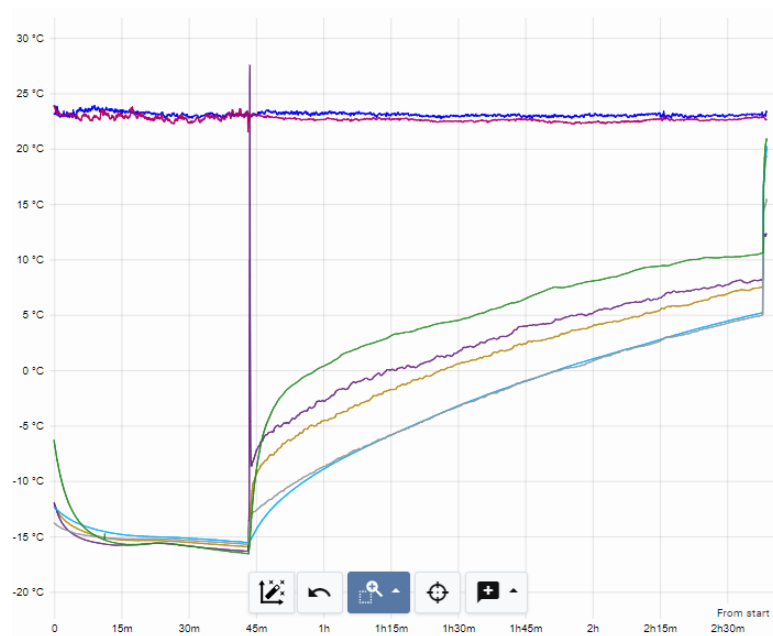


- Pry between cells and base to release cells from resin

10.8 Results

10.8.1 Cold Test

10.8.1.1 Temperature monitoring



The freezer available could only reach -18 the logger shows the temperature was reached between cells. Once removed plastic pry tools were pushed into the resin to no avail.

10.8.1.2 Size check

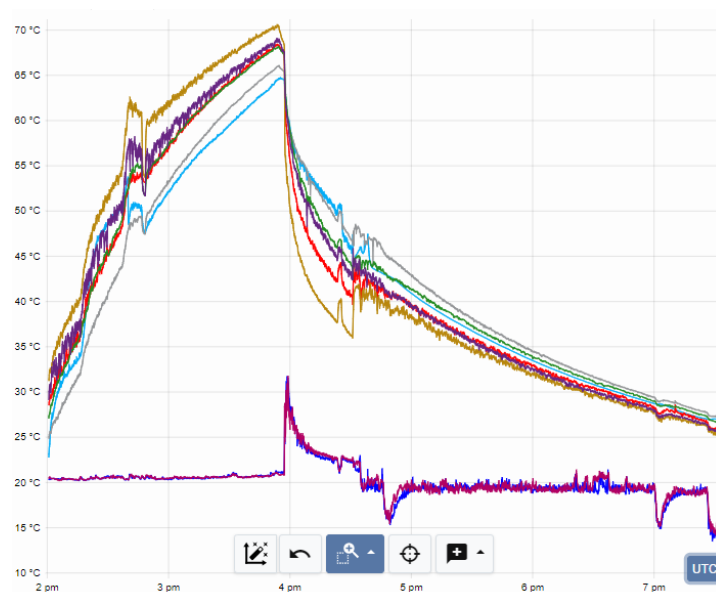
The module was remeasured to check if any noticeable gap or parting of the resin had occurred. No conclusive increase in size was noted.

10.8.1.3 Mass gained

The module was re weighed and a small increase in mass (11grams) was noted. This was believed to be due to condensation build up when freezing in the non-humidity-controlled freezer.

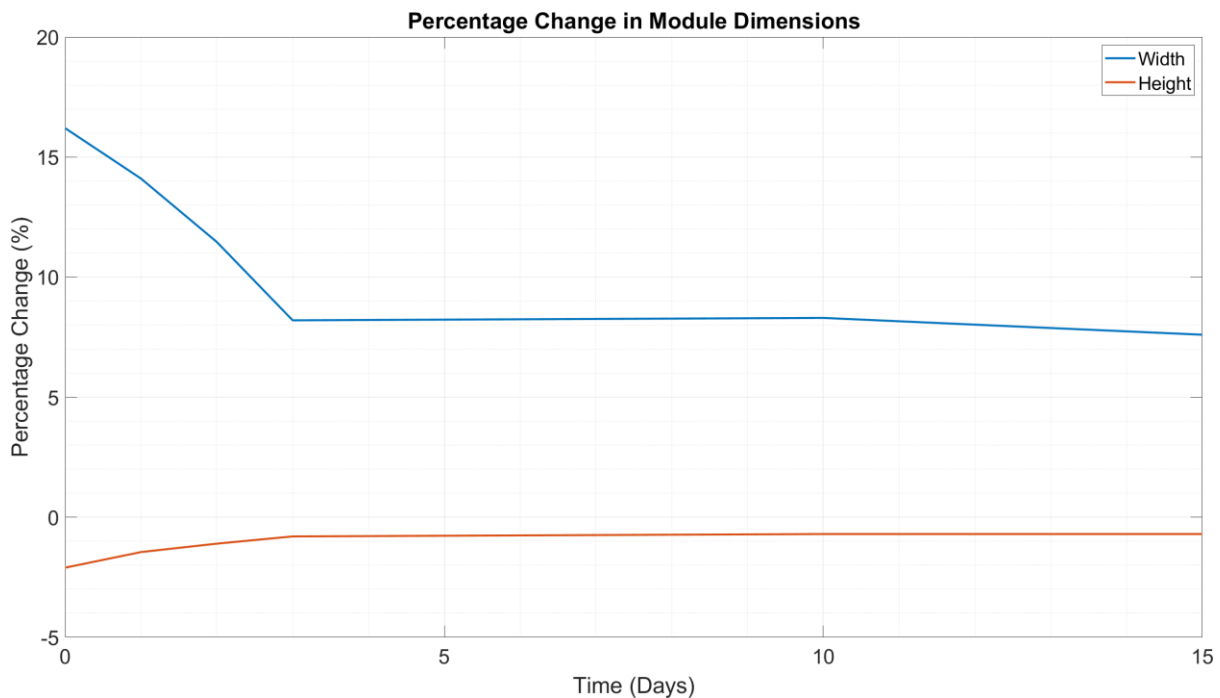
10.8.2 Hot Test

10.8.2.1 Temperature monitoring



During the temperature increase, the heater cut in and out causing the uneven rise in temperature. The increase in ambient temperature and the decrease in module temperature signifies the end of the exposure where the door opening increases the ambient temperature

10.8.3 Size increase



The above graph shows that the module increased by 16% in width due to chemical reactions within the cells. The exposed temperature was not excessively high, but the module had already been discharged past the safe cut off voltage.

10.8.4 Pressure applied in both tests

As the module was suspended upside-down by the base the area of the base and the modules mass of 10.9Kg meant the force due to gravity was 106 newtons and pressure of 2.028KPa across the entire base layer of resin. To try and penetrate the resin in a repeatable manner a blunt plastic pry tool was pushed in between the cells and the base with a mass of 10kg resting on it (the module had to be rotated) giving approximately 7.7Gpa of pressure at the tip which also failed to make inroads into the resin.

10.9 Discussion of thermal results

10.9.1 cold

Only mass increase was due to condensation build up freezing on module.

10.9.2 Hot

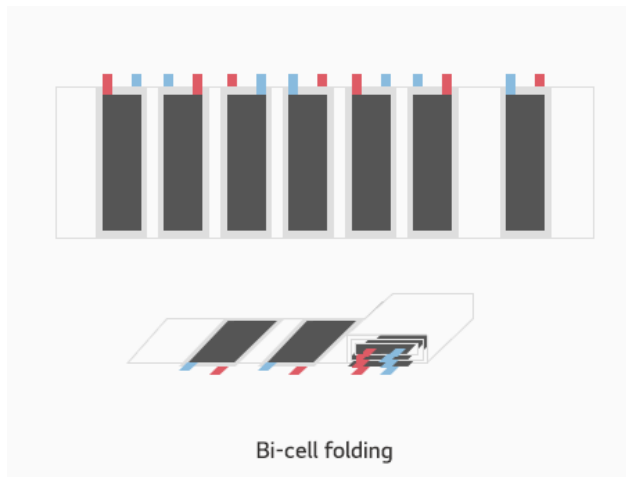


Figure 10 folded not rolled pouch (LG, no date)

The above figure shows that LG implement a cell folding technique where the anode and cathode are not continuous (LG, no date), preventing thickening creasing and cracking at the edges. As the increase observed during the heat test only occurred on the side plane of the cells it is believed that the cells on test have been fabricated in this manner.

Increase in cell volume is believed to be due to the fact the cells have already been damaged with excessive discharge (Liao *et al.*, 2017). Although they are within the believed safe window of temperature as they are baked to 80C in manufacturing it is unknown what state of charge (SoC) they are at or if they are in their pre charged no solid electrolyte interphase (SEI) state for the production heat exposure to raise air in the electrolyte to the top of the cells. If they are uncharged, all voltage is due to the electrochemical reactivity of different materials (Ahmadi *et al.*, 2014). In this state all the lithium is in the cathode and no ions have moved to the anode removing the potential for dendrite build up and lithium plating. As the test performed in this report was on a used module that had been fully charged, cycled and then discharged past the safe low voltage SoC threshold dendrite and plating would have started within the cells and then potentially accelerated in the high temperature exposure test performed on the resin causing the volume increase in the cells.

11 Discussion

The breakdown of the LG module poses many problems as the cell pouches are thin and the epoxy resin is strong simply taking them out is not possible. If they were to be taken apart at a high SoC to give second life to working cells that could not be drained due to an open circuit in the module further analysis of the dangers posed by high SoCs must be undertaken as planned in the appendix.

If the modules were to be recycled and not reused when they have issues many steps could be taken to mitigate risks.

- Full Drain where possible ignoring risk of dendrite
- Freezing modules prior to crushing to stop electrochemical reactions
- Magnets and shake plate so separate frozen materials by size and density
- Perform crushing and sorting in inert atmosphere to reduce fire risk
- Automate as much as possible to reduce risk to operators
- Separate reactive materials and store in adequate containers

If the modules were to be cut through cutting through faulty cells as a way of separating reusable cells a reactive chemistry analysis should take place performing a full product hazard analysis. This poses many problems as the organic chemistry that makes up the electrolyte is intellectual property of the manufacturer as is the exact composition of the cathode.

The initial cell safety test proposed in the appendix is mainly concerned with the safe SoC working with reactive chemicals also have the potential to scale up exponentially. The USCSB carried out a report on such an explosion at a plastics factory (Synthron Chemical Explosion, 2007) where operators were ignorant to the potential dangers and added 12% to a recipe which doubled the reaction heat output.

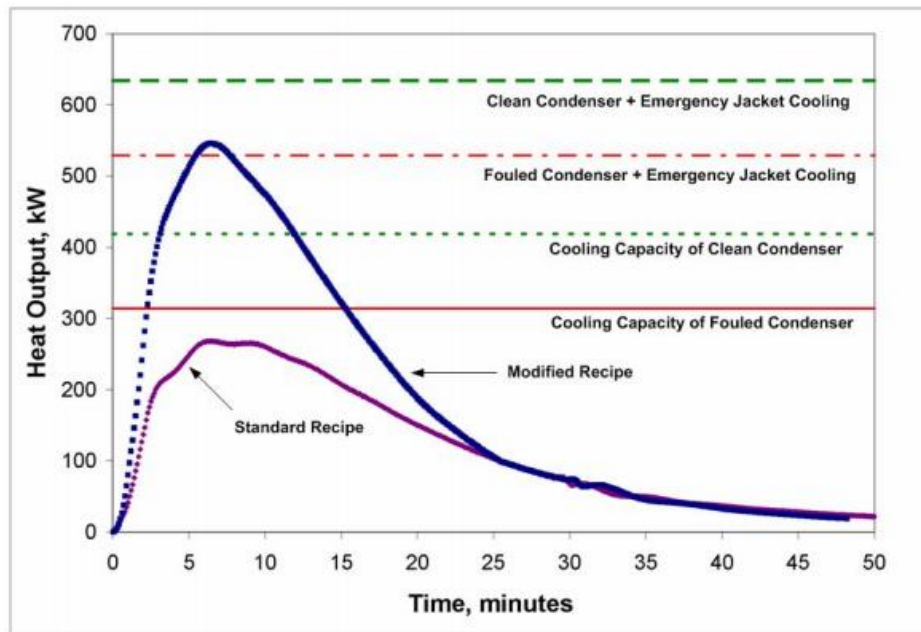


Figure 11 Scale up danger (Synthron Chemical Explosion, 2007)

The graph above shows the exponential increase for a small increase in product. The report also criticised the company for having no chemical engineers' assess the operations change in batch size. the disassembly of the modules in question is not standard practice and cannot be covered by the mitigating risks bullet pointed above as they would damage any cells making them dangerous for second life. An additional report by the USCSB criticised a chemical waste plants lack of safety automation (CSB, 2002) with no gas alarms heat sensing alarms and separation barriers to stop fires spreading after a fatal incident where material handling was automated, but safety was not. Realistically the task would need a multi discipline team containing:

- Chemical Engineer with expertise in reactive chemistry
- An organic chemist for the electrolyte
- An engineer with expertise in Safety Automation

Recycling facilities of Lithium ion batteries currently charge to receive them. this is because the raw materials are less valuable then the cost of extraction. Once down to the separated crushed material pyrometallurgy must be performed to remove the cobalt and hydrometallurgy for the lithium. These methods have already been refined by the likes of Duesenfeld GmbH. To move to separating the cells first would be more expensive for the previous reasons and as there are no subsidies available for that process currently it may prove uneconomical.

12 Conclusions

The discharge test was not done the standard way to assess LIBs (Miao *et al.*, 2019), but this was due to the high energy density and unavailability of high enough power constant current machine. There was one available that could pull at 1 amp but that would take 10 days to complete. high energy density of the modules meant the danger with shorting was conducted heat into the module rather than the heat rise due to high current output as an extremely low resistance would be needed to get above 1C rate.

Although the energy recovery had enough instantaneous power to pop a 30 amp fuse the only danger would be from sparks igniting other ignition sources therefore an inert e.g. nitrogen environment would be safer to work with them (Qiao *et al.*, 2019). the completely drained modules do pose a danger if they are not separated when stored as there is a massive danger if charged the dendrite often causes an internal short.

To remove the casing some form of machining will need to take place. The DTI merely proved the inaccuracy in the machine. The slow pulling method used may have also added creep further skewing results. for more accurate results

as the epoxy resin would not breakdown with temperature any other methods such as solvents, cutting and vibrations would create further hazards from additional COSH problems and likely damage the cells. The large increase in width could be due to the damaged drained cells and that they may have silicone mixed in the anode this increases capacity (these are high capacity cells) but makes the cells mechanically unstable (they are already partially swelling their case).

13 further work / Pandemic

up to the 12th of march I was on track with all physical testing that I could get support for completed. Most of the research read in preparation for my weekly meetings with Treharne but not yet written to an academic standard.

- Then my daughter had tonsillitis and as university stopped, I looked after while her off school taking away project and assignment time.
- Schools closed on the 18th of march and as my partner is a key worker, I have taken sole full-time care of our 2 children with all spare time spent preparing for home schooling etc.
- Due to the back log of work I spent the weekends of the 25th of April and 2nd of May at my mothers, to work as I cannot with 2 small children at home. The first weekend was spent on a FEA assignment and restarting project work.
- The second weekend was to try and cram in an entire report but upon arrival Friday afternoon the hospital rang to inform of my grandfather passing away and early Friday evening was spent calling relatives and intermittently throughout the weekend eating into work time.

The following was already listed before march to complete with the sections in red in detail.

Project

1. Full research
 - Why recycle
 - Complete recycle
 - Second life
 - Open loop
 - Closed loop
 - Regulations (nrw,wee,un38.3)
 - Module chemistry
 - Current automated (battery, module, cell and material)
 - Current manual (battery, module, cell and material)
2. Detailed Cell chemistry
 - Nmc in question
 - Soc
 - Soh
 - Impact environment creation and waste
3. Energy use
 - Tris decision
 - Total loss and recovery
 - Realistic and total quantities
 - Hydrogen
 - Ground storage
 - Resistor drain
 - Drain MATLAB App
 - Methane

- Water pump
- Water bath
- Back to grid
- Decision matrix
- 4. Detailed Module Drain Management
 - Voltage drop test results
 - Constant current / constant load
 - Series quantity parallel quantity
 - Hall effect
 - Volt switches
- 5. Strip down of modules
 - Casing
 - Denison test
 - Weld thickness
 - CAD free cutting zones
 - Heat test, force, energy in
 - Cold test, force, energy in
 - Vibration
 - Chemical
 - Glue
 - Thermal resin
 - Busbar tabs
 - Plastics
 - Loom
- 6. Extra
 - Soc safety tests
 - Soh safety test penetrate, short, standard practices
 - Voltage recovery
 - Electro chemical difference
 - Drain expansion & temp
 - Thermal expansion
- 7. Conclusion
 - Need for recycling
 - Second uses
 - Removing cells
- 8. Appendicitis
 -

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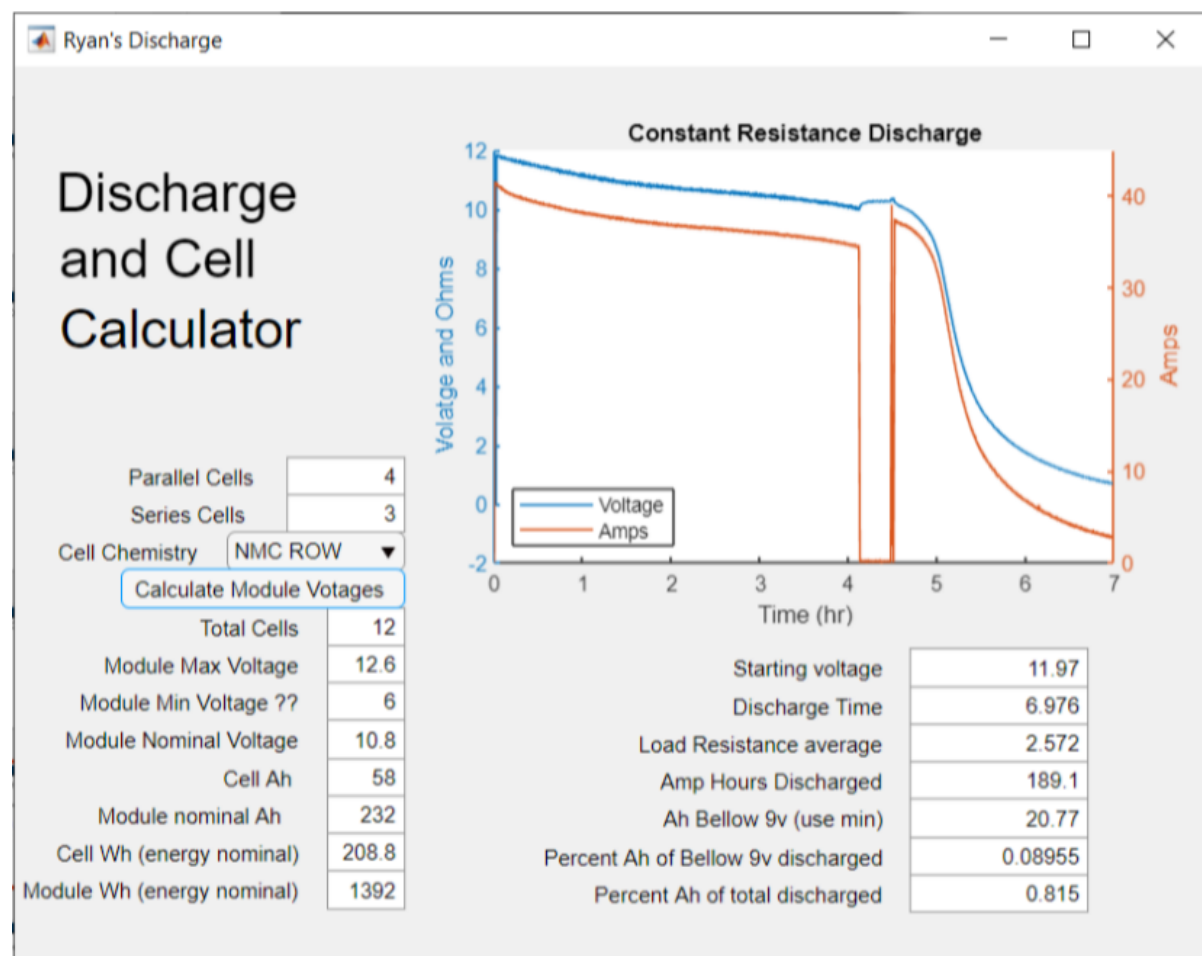
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15 Appendices

15.1 Discharge App



15.2 BEV PHEV MH Vehicle Sales UK

Table 1 BEV PHEV MH new registrations per month August 2009-2019

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Jan		1844	1800	2119	2287	2859	4598	6072	7279	9020	11014
Feb		680	636	659	834	1212	1852	2221	3308	3547	4521
Mar		3572	5326	5420	5318	8713	14332	17414	22818	24126	25302
April		1341	1986	1839	1858	2949	5010	6356	6274	9102	10254
May		1704	1599	2108	1999	3444	5021	4631	8258	10872	12142
June		2327	1679	2481	3131	4160	7150	8311	10721	15549	15079
July		1878	1425	2079	2432	3294	4310	5379	8871	10734	13106
Aug	776	689	608	655	926	1259	1917	2507	3968	7489	9070
Sep	3958	4176	4807	4700	6387	9958	12113	16052	22628	23507	40917
Oct	1328	1510	1589	2206	2952	4711	5360	6021	8244	10597	14231

Nov	977	1752	2146	1927	2372	4906	5321	6661	8867	10769	
Dec	986	1392	1855	1648	2235	4388	5805	6266	8585	8895	
Total	8025	22865	25456	27841	32731	51853	72789	87891	119821	144207	155636

(Society of Motor Manufacturers and Traders, 2019)

15.3 System of Safe work For

15.3.1 Understanding LG and Samsung Cell Energy

1. Discharge modules to manufacturer's running 0%
2. Manually strip module to cell level
3. Perform state of health checks and SOC tests leaving cells at SOC for next stage
4. Penetration cell tests
5. Shorting cell tests

15.3.2 Discharge modules to manufacturer's running 0%

Workspace

Location and warnings and general safety	• Outside the workshop signs should be used to warn for, risk of fire, risk of gas release. • The area in the workshop should be cordoned off with barriers to give a 3m exclusion zone. • Only one module within the exclusion to be present to be worked on at a time. • The area should be near the external doors for ventilation and evacuation if necessary.
Worktop	• A nonconducting worktop or cover should be used on the bench to prevent shorting the terminals or busbars.
Extractor	• This should be available to remove and vented gases
Water	• For any burns from heat or hydrochloric acid in the event of hydrogen fluoride releasing (this must be kept sealed as hydrogen fluoride will react with it to make hydrochloric acid).

PPE

Fire extinguisher class D	In case of accidental thermal runaway
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Tools

Insulating tape	To cover terminals
Thermal imaging camera	To monitor heat to check for thermal runaway
Socket and ratchet	To attach terminals to load device
Electronic load 2380-500	To discharge modules

In case of emergency

Fire	Have workstation set up with clear access to an emergency exit. Should excessive temperature(s)/ fire occur, with the module in situ on the mobile workstation, remove the module to an outside area where it poses minimal risk to others and the surrounding area. If fire cannot be controlled by aid of a handheld fire extinguisher, contact emergency services for assistance.
Explosion	Risk of explosion should be at a minimum as a thermal imaging tool should always be used to monitor the possibility of rising temperatures. However, if an explosion does occur and the second nominated person is able, they should immediately contact emergency services and sound the fire alarm should the explosion have transferred high temperature to other areas that become at risk of combustion.
Chemical	If disassembly of the module results in unintentional penetration of a cell internal to the module, the particulate face mask and eye protection should aid the individual in minimising inhalation/ consumption and/ or absorption of foreign bodies via the eyes or orally. If any chemicals from the module enter the eyes/ body, immediately address the concern with the assistance of a first aid trained individual whilst also ensuring

	medical evaluation is sought by the appropriate professionals. Alternatively, should there be a release of chemicals into the air of the working environment. Ensure the area is well ventilated whilst monitoring the unit (for thermal runaway etc) and removing it from the area of concern to an agreed location at soonest convenience.
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Method

1. Set the load device to draw at the agreed c rate for the module and to stop at an agreed voltage.
2. Set up the thermal camera to monitor the module.
3. Attach the load device to the module and discharge the module.
4. Record maximum temperatures for the c rate
5. Mark the module as discharged to manufacturer's running 0%

15.3.3 Strip module to cell

Workspace

Location and warnings and general safety	• Outside the workshop signs should be used to warn for cutting, use of power tools, risk of fire, risk of gas release. • The area in the workshop should be cordoned off with barriers to give a 3m exclusion zone. • Only one module within the exclusion to be present to be worked on at a time. • The area should be near the external doors which should be open for ventilation and evacuation if necessary. • Two people should be present to carry out the task.
Worktop	• A nonconducting worktop or cover should be used on the bench to prevent shorting the terminals or busbars.
Extractor	• This should be available to remove and vented gases
Water	• For any burns from heat or hydrochloric acid in the event of hydrogen fluoride releasing (this must be kept sealed as hydrogen fluoride will react with it to make hydrochloric acid).

PPE

Gloves Chemical and Cut Resistant (Showa KV660)	Protect hands from cuts and leaks
Fire jacket (ATPV = 12 cal/cm ²)	Protect from burns from thermal runaway
Overalls fire rated Iso 7000-2417	Protect from burns from thermal runaway
Face shield with respirator (type E Filter)	Protect eyes from acid and stop fumes and dust/ swarf from entering the respiratory system.
Fire extinguisher class D	In case of accidental thermal runaway

Tools

Insulating tape	To cover terminals
Hacksaw	To cut through and weaken case
Separating jig	To pull two sections of case apart
Thermal imaging camera	To monitor heat to check for thermal runaway
Socket and ratchet	To drive jig
Plastic L bracket and terminal bolt	To hold internals of module into 1 half of case in initial separation
Dremel	To cut through case if jig fails
voltmeter	To check module is discharged
Snips	To cut busbars
knife	To cutaway module inner foam cover

In case of emergency

Fire	Have workstation set up with clear access to an emergency exit. Should excessive temperature(s)/ fire occur, with the module in situ on the mobile workstation, remove the module to an outside area where it poses minimal risk to others and the surrounding area. If fire cannot be controlled by aid of a handheld fire extinguisher, contact emergency services for assistance.
explosion	Risk of explosion should be at a minimum as a thermal imaging tool should always be used to monitor the possibility of rising temperatures. However, if an explosion does occur and the second nominated person is

	able, they should immediately contact emergency services and sound the fire alarm should the explosion have transferred high temperature to other areas that become at risk of combustion.
Chemical	If disassembly of the module results in unintentional penetration of a cell internal to the module, the particulate face mask and eye protection should aid the individual in minimising inhalation/ consumption and/ or absorption of foreign bodies via the eyes or orally. If any chemicals from the module enter the eyes/ body, immediately address the concern with the assistance of a first aid trained individual whilst also ensuring medical evaluation is sought by the appropriate professionals. Alternatively, should there be a release of chemicals into the air of the working environment, ensure the area is well ventilated whilst monitoring the unit (for thermal runaway etc) and removing it from the area of concern to an agreed location at soonest convenience.
Mechanical/power tool injury	If disassembly of the module results in unintentional injury, immediately address the concern with the assistance of a first aid trained individual whilst also ensuring medical evaluation is sought by the appropriate professionals.

Method For LG

1. The module must be checked it has been marked as discharged and then an additional check should be carried out with the voltmeter.
2. The plastic L clamp is to be secured the negative terminal to hold the cell pack to the negative end cap during the first part of case removal.
3. The terminals are taped to avoid shorting.
4. Thermal imaging tool should be set up to monitor heat.
5. The case is weakened with a hacksaw around its centre avoiding cutting all the way through the top as loom for the 12-pin connector is beneath.
6. The jig is inserted through the bolt holes and the two halves are pulled apart either braking at weakened points or end cap welds.
7. The jig is removed, and the positive side is slid off.
8. The plastic L clamp is removed from the negative terminal and the negative half is slid off the cell pack.
9. If the two halves cannot be slid off, cut away more of the casing as necessary.
10. Dremel or snip the busbars off the cells.
11. Remove busbar frame and inner covers.
12. Separate modules into 3 packs in series putting 2 a safe distance away.
13. Remove connectors joining cells in series with snips or Dremel.
14. Tape off cell connections.
15. Repeat for other 2 packs in series.

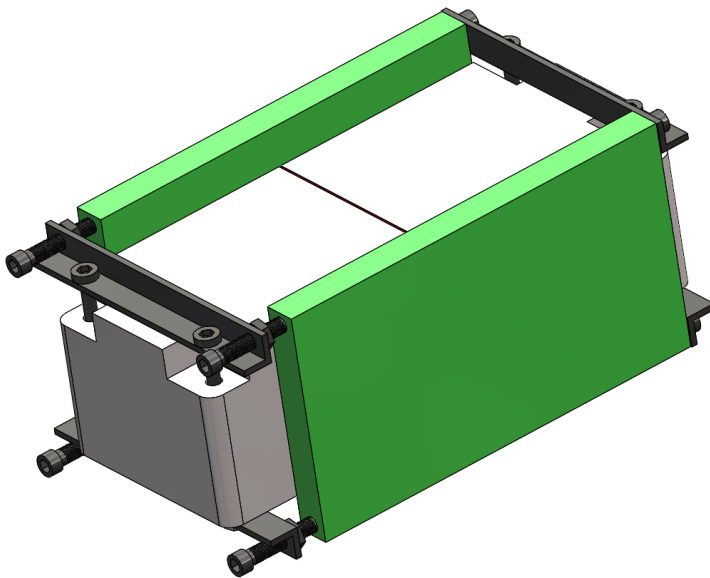


Figure 12 case splitting jig (green nonconductive high-density model board)

15.3.4 Perform state of health checks and SOC tests leaving cells at SOC for next stage

Workspace

Location and warnings and general safety	• Outside the workshop signs should be used to warn for risk of fire, risk of gas release. • The area in the workshop should be cordoned off with barriers to give a 3m exclusion zone. • Only one cell within the exclusion to be present to be worked on at a time. • The area should be near the external doors for ventilation and evacuation if necessary. • Two people should be present to carry out the task.
Worktop	• A nonconducting worktop or cover should be used on the bench to prevent shorting the terminals or busbars.
Extractor	• This should be available to remove and vented gases
Water	• For any burns from heat or hydrochloric acid in the event of hydrogen fluoride releasing (this must be kept sealed as hydrogen fluoride will react with it to make hydrochloric acid).

PPE

Fire extinguisher class D	In case of accidental thermal runaway
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Tools

Insulating tape	To cover terminals
Temperature probes and Pico scope	To monitor heat at c rates and to check for thermal runaway.
Electronic load 2380-500	To Discharge cells and test state of health and for discharging to required state of charge.
Power supply EA-PS 5000A	To charge cells at known c rates.

Leads and connectors	Test leads and connectors to join to cells.
----------------------	---

In case of emergency

Fire	Have workstation set up with clear access to an emergency exit. Should excessive temperature(s)/ fire occur, with the module in situ on the mobile workstation, remove the module to an outside area where it poses minimal risk to others and the surrounding area. If fire cannot be controlled by aid of a handheld fire extinguisher, contact emergency services for assistance.
explosion	Risk of explosion should be at a minimum as a thermal imaging tool should always be used to monitor the possibility of rising temperatures. However, if an explosion does occur and the second nominated person is able, they should immediately contact emergency services and sound the fire alarm should the explosion have transferred high temperature to other areas that become at risk of combustion.

Chemical	If disassembly of the module results in unintentional penetration of a cell internal to the module, the particulate face mask and eye protection should aid the individual in minimising inhalation/ consumption and/ or absorption of foreign bodies via the eyes or orally. If any chemicals from the module enter the eyes/ body, immediately address the concern with the assistance of a first aid trained individual whilst also ensuring medical evaluation is sought by the appropriate professionals. Alternatively, should there be a release of chemicals into the air of the working environment, ensure the area is well ventilated whilst monitoring the unit (for thermal runaway etc) and removing it from the area of concern to an agreed location at soonest convenience.
----------	--

Method

1. Perform state of health tests current pulsing with electronic load.
2. Completely discharge 2 Samsung and 2 LG for future cell strip down
3. Charge the cells to fully charged and discharge with the electronic load graphing voltage at different c rates to see the voltage under load at a given state of charge whilst monitoring temperatures.
4. Charge and discharge cells to all the required levels for nail and shorting tests (2 Samsung and 2 LG at 30,45,60,80 and 100%)
5. Mark all the cells SOH and SOC.
6. Re tape contacts.

15.3.5 Penetrate cells

Workspace

Location and warnings and general safety	• Outside the workshop signs should be used to warn for risk of fire, risk of gas release. • The area in the workshop should be cordoned off with barriers to give a 3m exclusion zone. • Only one cell within the exclusion to be present to be worked on at a time. • The area should be near the external doors which should be open for ventilation and evacuation if necessary. • Two people should be present to carry out the task.
Test rig	• A drop test rig that can be operated remotely must be used.
Extractor	• This should be available to remove and vented gases
Water	• For any burns from heat or hydrochloric acid in the event of hydrogen fluoride releasing (this must be kept sealed as hydrogen fluoride will react with it to make hydrochloric acid).

PPE

Gloves Chemical and Cut Resistant (Showa KV660)	Protect hands from cuts and leaks
Fire jacket (ATPV = 12 cal/cm ²)	Protect from burns from thermal runaway
Overalls fire rated Iso 7000-2417	Protect from burns from thermal runaway
Face shield with respirator (type E Filter)	Protect eyes from acid and stop fumes and dust/ swarf from entering the respiratory system.
Fire extinguisher class D	In case of accidental thermal runaway
Welders Gauntlets	To move tested tray whilst hot

Tools

Insulating tape	To tape down cells
Drop test rig	To remotely penetrate cells
High speed camera	To monitor reaction
Thermal imaging camera	To monitor heat from reaction

In case of emergency

Fire	Have workstation set up with clear access to an emergency exit. Should excessive temperature(s)/ fire occur, from the penetrated cell, remove the cell to an outside area where it poses minimal risk to others and the surrounding area. If fire cannot be controlled by aid of a handheld fire extinguisher, contact emergency services for assistance.
Explosion	During the penetration tests there is a high risk of explosion. The dangers posed by this should be kept to a minimum by ensuring that nothing else in the test area is combustible, no person is in clear line of sight from any debris and the test rig is operated remotely. However, if any incidents occur a second nominated person should alert relevant professionals e.g. first aider, emergency services.
Chemical	During penetration of the cells, the particulate face mask and eye protection should aid the individual in minimising inhalation/ consumption and/ or absorption of foreign bodies via the eyes or orally. If any chemicals from the module enter the eyes/ body,

	immediately address the concern with the assistance of a first aid trained individual whilst also ensuring medical evaluation is sought by the appropriate professionals. Alternatively, should there be a release of chemicals into the air of the working environment, ensure the area is well ventilated whilst monitoring the unit (for thermal runaway etc) and removing it from the area of concern to an agreed location at soonest convenience.
Mechanical injury	If penetrating the cells results in unintentional injury, immediately address the concern with the assistance of a first aid trained individual whilst also ensuring medical evaluation is sought by the appropriate professionals.

Method

1. The test rig should be checked and the additional safety pin is inserted.
2. The thermal camera and high frame rate camera must be set up behind screens and focused on test site.
3. Select the lowest energy density and state of charge cell for the first test (Samsung 30%).
4. The cell is to be taped to the metal tray at the bottom of the test rig.
5. The thermal camera must be started.
6. The pin must be removed from test rig.
7. The operators should move out of a direct line of sight.
8. Remotely the high frame rate camera must be started.
9. The nail with weights is dropped and the test is recorded.
10. Using welders' gauntlets move the tested cell and tray away to cool whilst setting up spare tray.
11. After assessing the reaction if deemed safe the test is repeated and then the state of charge increased whilst assessing safety throughout.

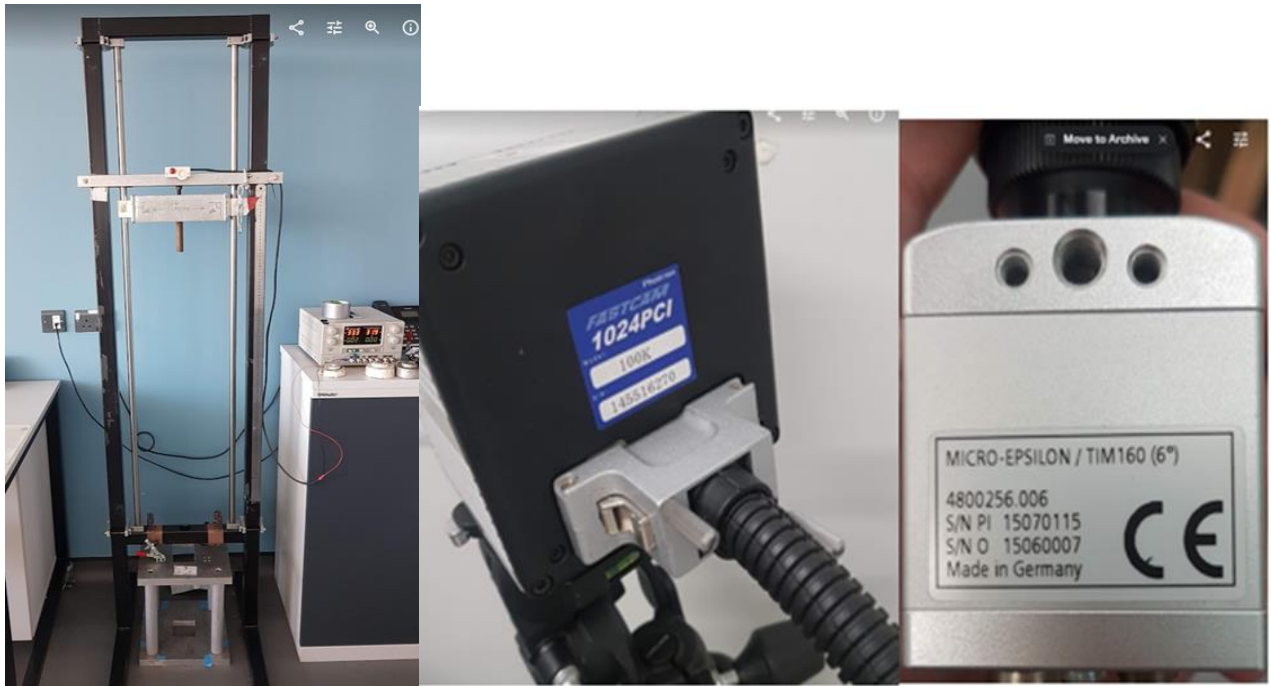


Figure 13 nail tester, high speed camera and thermal camera.

15.3.6 Short Cells

Workspace

Location and warnings and general safety	• Outside the workshop signs should be used to warn for risk of fire, risk of gas release. • The area in the workshop should be cordoned off with barriers to give a 3m exclusion zone. • Only one cell within the exclusion to be present to be worked on at a time. • The area should be near the external doors which should be open for ventilation and evacuation if necessary. • Two people should be present to carry out the task.
Extractor	• This should be available to remove and vented gases
Water	• For any burns from heat or hydrochloric acid in the event of hydrogen fluoride releasing (this must be kept sealed as hydrogen fluoride will react with it to make hydrochloric acid).

PPE

Gloves Chemical and Cut Resistant (Showa KV660)	Protect hands from cuts and leaks.
Fire jacket (ATPV = 12 cal/cm ²)	Protect from burns from thermal runaway.
Overalls fire rated Iso 7000-2417	Protect from burns from thermal runaway.
Face shield with respirator (type E Filter)	Protect eyes from acid and stop fumes and dust/ swarf from entering the respiratory system.
Fire extinguisher class D	In case of accidental thermal runaway.
Welders Gauntlets	To move test trays whilst hot.

Tools

Insulating tape	To tape down cells
Wires	To short cells
High speed camera	To monitor reaction
Thermal imaging camera	To monitor heat from reaction

In case of emergency

Fire	Have workstation set up with clear access to an emergency exit. Should excessive temperature(s)/ fire occur, from the shorted cell, remove the cell to an outside area where it poses minimal risk to others and the surrounding area. If fire cannot be controlled by aid of a handheld fire extinguisher, contact emergency services for assistance.
explosion	During the shorting tests there is a high risk of explosion. The dangers posed by this should be kept to a minimum by ensuring that nothing else in the test area is combustible, no person is in clear line of sight from any debris and the test rig is operated remotely. However, if any incidents occur a second nominated person should alert relevant professionals e.g. first aider, emergency services.
Chemical	During shorting of the cells, the particulate face mask and eye protection should aid the individual in minimising inhalation/ consumption and/ or absorption of foreign bodies via the eyes or orally. If any chemicals from the module enter the eyes/ body,

	immediately address the concern with the assistance of a first aid trained individual whilst also ensuring medical evaluation is sought by the appropriate professionals. Alternatively, should there be a release of chemicals into the air of the working environment, ensure the area is well ventilated whilst monitoring the cell and removing it from the area of concern to an agreed location at soonest convenience.
--	---

Method

1. The thermal camera and high frame rate camera must be set up behind screens and focused on test site.
2. Select the lowest energy density and state of charge cell for the first test (Samsung 30%).
3. The cell is to be taped to the metal tray.
4. The thermal camera must be started.
5. The operators should move out of a direct line of sight.
6. Remotely the high frame rate camera must be started.
7. The cell is shorted remotely, and the test is recorded.
8. Using welders' gauntlets move the tested cell and tray away to cool whilst setting up spare tray.
9. After assessing the reaction if deemed safe the test is repeated and then the state of charge increased whilst assessing safety throughout.

15.4 Risk Assessed Work Certificate

RISK ASSESSED WORK CERTIFICATE

RAWC No.

Applicable to work/testing activities carried out in accordance with Lithium Ion Cell Test Rules

Location:	Prescribed Test Area?	Yes	No

Work/testing to be carried out on:					
Description of work or testing and SSOW No:					
Person-in-Charge responsible for the work/testing: Last HV training date: If more than 6 months, speak to your manager.	(Print name) Date:				
PART 1: Confirmation of safety checks before ANY work/testing starts in Test Area (N/A = Not Applicable)					
General Safety:	Test Area environment in a satisfactory condition for work/testing	YES			
Electrical Hazards	All electrical supplies used for testing - isolated and locked off	YES	N/A		
Mechanical Hazards	Risk from stored energy or moving parts - adequately controlled	YES	N/A		
Thermal Hazards	Risk from Hazardous Temperatures - adequately controlled	YES	N/A		
Chemical Hazards	Risk from Chemical hazards - adequately controlled	YES	N/A		
Status Signs	RED 'Serious Health Hazard' sign displayed	YES			
Risk Assessment Completed by:	(Sign): 	Date: 	Time: 		
PART 2: Working Party Control Briefing Confirmation					
Working Party Control	Working Party has been briefed and have signed on to 'Working Party Control Sheet' (separate sheet attached)	YES			
Person-in-Charge confirmation	(Sign): 	Date: 	Time: 		
PART 3: Confirmation of Control Measures BEFORE commencing testing on Defined Apparatus					
	16 RISK	16.1 CONTROL MEASURE			Control measure identified & applied

A. General Safety			
A1	Access to Test Area is not adequately controlled	Verify that access is restricted to appropriately trained Senior Authorised Persons	
A2	Risk of slipping, tripping or falling	Verify that access to and from the work/test area is safe	
A3	Risk from other non-related equipment or materials present in the test area	Verify safety measures applicable to hazards from other non-related equipment or materials are in place	
		Verify any combustible materials non-related removed from the area	
A4	Other non-related activities in progress at the same time	Verify that any concurrent activities will not interfere/affect the proposed work/test activities	
A5	Risk of muscular or skeletal injury through the incorrect lifting and moving of test equipment or components	Appropriate lifting and moving techniques to be employed	
B. Electrical Hazards			
B1	Risk of burns due to arcing flashover (arc-flash) from the short circuiting of Conductors .	Exposed Conductors which are or could be Live are screened by means Approved insulating material	
		Access to Test Area is prevented whilst testing (if applicable)	
		Confirmation that proposed work/test activities will be carried out in accordance with a Safe System of Work which will prevent the short circuiting of conductors.	
		Approved PPE is available for use as specified in Safety Rules	

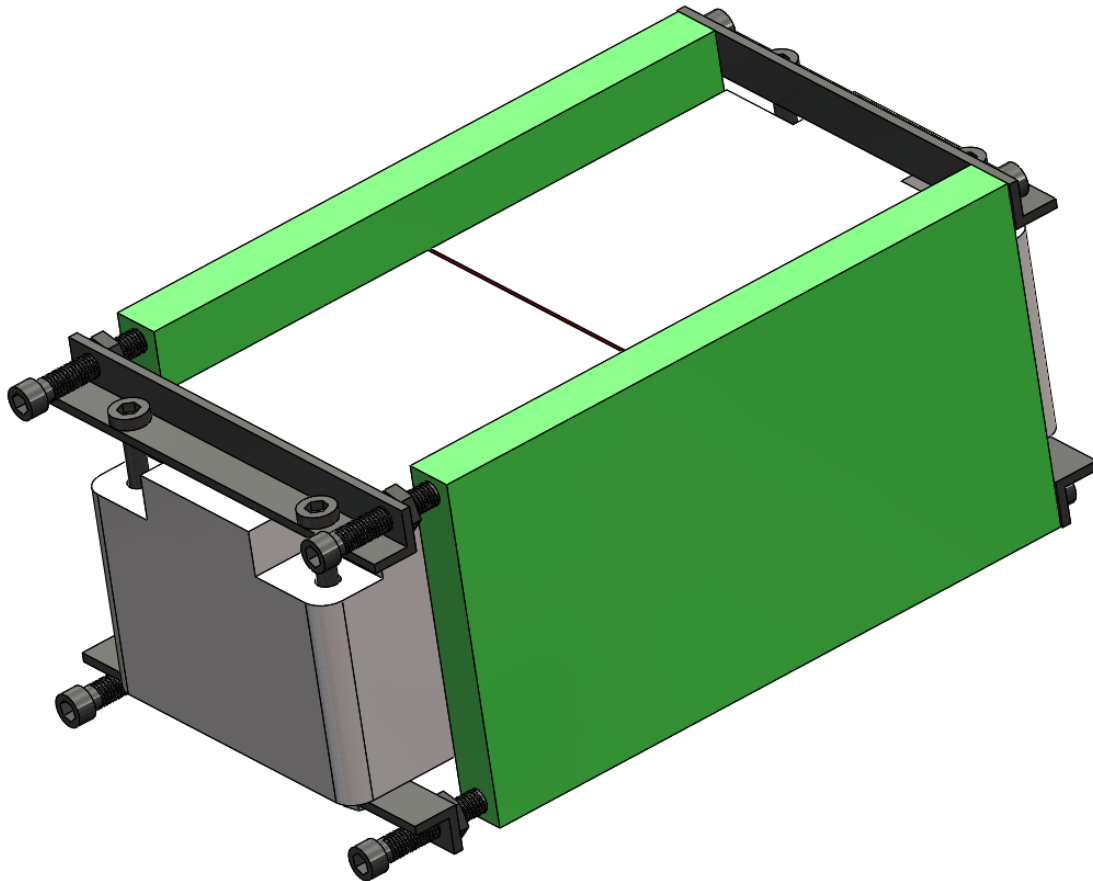
Continued overleaf

C. Mechanical Hazards			
C1	Risk of contact or entrapment with moving mechanical components	Verify that adequate guarding/shielding in place to prevent accidental or inadvertent contact with moving mechanical parts	
		Verify Safety pins inserted into Mechanical Device.	
C2	Risk of items of clothing or jewellery being caught in moving mechanical components	Verify that all Persons are wearing appropriate PPE and that items of jewellery and clothing is removed or secured	
D. Thermal Hazards			

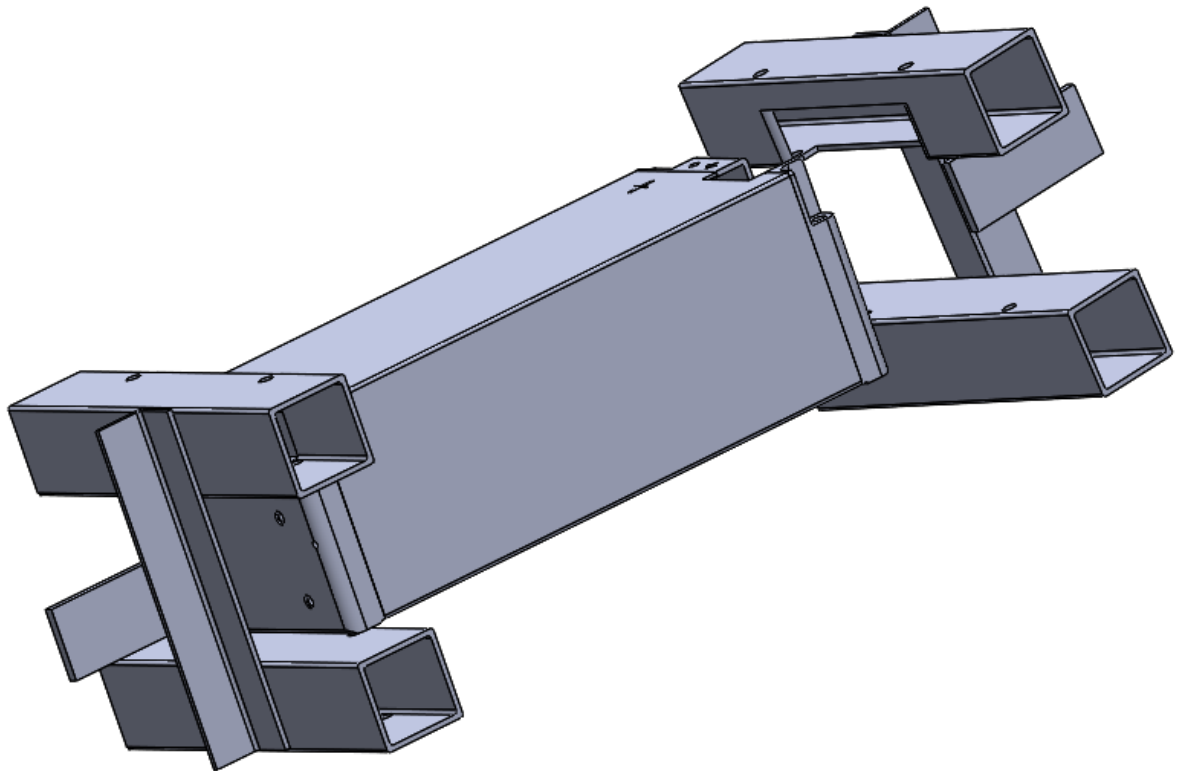
D1	Risk of burns through contact with materials, gases or fluids operating at high temperatures	Confirmation that proposed work/test activities will be carried out in accordance with a Safe System of Work which will prevent the risk of burns.	
		Verify that appropriate safety measures and PPE are in place to prevent the risk of burns	
		Monitoring process in place to monitor or test for Hazardous Temperatures	
E. Chemical Hazards			
E1	Risk of burns, ingestion, inhalation or absorption from toxic or corrosive chemicals	Confirmation that proposed work/test activities will be carried out in accordance with a Safe System of Work which will prevent the risk of exposure to harmful chemicals	
		If there is a risk, can suitable safety measures be applied to safeguard persons?	
		Verify that appropriate safety measures and PPE are in place to prevent the risk from chemical burns and inhalation	
F. Noise Hazards			
F1	Risk of hearing damage due to excessive noise	Verify that Persons will not be exposed noise levels which could be harmful	
		Where Persons could be exposed to harmful noise levels is suitable personal hearing protection available in accordance with HSE guidelines.	
G. Other Hazards			
G1			
Additional Precautions:			
Are the following Safety provisions in place?			
(a) Emergency response procedures known and understood			☐ Yes
(b) PPE applicable for the work/testing activity is available			☐ Yes
(c) Second Person nominated to accompany Person-in-Charge			☐ Yes
(d) Test Area Status Signs:			
	Red 'Serious Health Hazard' sign displayed		☐ Yes
(e) Emergency STOP buttons operating correctly			☐ N/A ☐ Yes
(f) All members of Working Party briefed on Control Measures detailed in Part 3 and SSOW?			☐ Yes
Risk Assessment Completed by:	(Sign) being the Person-in-Charge		Date:

			Time:
Nominated Second Person	(Sign)	(Print name)	Date:
			Time:
CANCELLATION: I confirm that this Certificate is cancelled and that all persons involved in the work/testing have been advised that no further work/testing is permitted AND that ALL testing energy sources have been isolated and locked off. Signed: _____ being the Person-in-Charge Time: Date:			

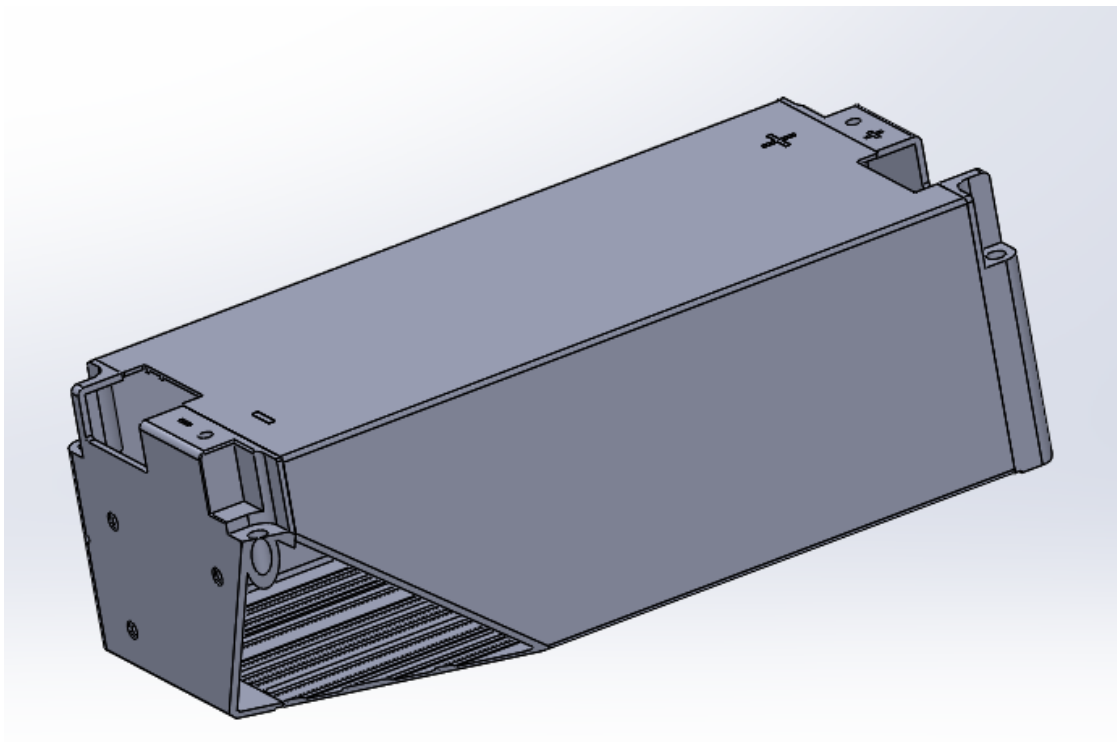
16.2 First puller



16.3 Puller for Denison Tester



16.4 Casing CAD



16.5 Recovering mains connection

Energy Recovery at 10 Tonnes per day (based on recovering energy on working days)

Previously Agreed figures 900KWh per day = 112.5 KW each working hour

Require: 112.5 KW DC to AC converter (for maximum use)

Using Onsite (Embedded Generation) between 150KWh (January per working day) and 97.5KWh (August per working day)

12.1875KW used onsite each working hour in august $\therefore$ Approved Export meter maximum 100.3125KW (Distributed Generation)

Previously agreed figure of 0 to 802.5KWh excess energy to recover per day (100.3125KW Each hour 8-hour day or 33.4375KW for 24h day)

.....
.....

Looking at I-pace Battery pack energy density

Energy density / Wh/kg	148.8 / 138.4
------------------------	---------------

I-Pace Pack has an energy density of 148.8Wh/Kg when fully charged $\therefore$ max 10 tonnes 1488KWh

1488kWh during 8hour day = 186KW

Require: 186KW DC to AC converter (for maximum use)

Using Onsite (Embedded Generation) between 150KWh (January per working day) and 97.5KWh (August per working day)

12.1875KW used onsite each working hour in august $\therefore$ Approved Export meter maximum 173.8125KW (Distributed Generation)

With LG modules 0 to 1390.5KWh excess energy to recover per day (173.8125KW Each hour or 57.9375KW per 24h day).

.....
.....

Looking at Module Level for highest energy density module.

Energy density / Wh/kg	192.7 / 180.7
------------------------	---------------

LG module has an energy density of 192.7Wh/Kg when fully charged $\therefore$ max 10 tonnes
1927KWh

1927kWh during 8hour day = 240.875kw

Require: 240.875Kw DC to AC converter (for maximum use)

Using Onsite (Embedded Generation) between 150KWh (January per working day) and 97.5KWh (August per working day)

3.242KW used onsite each working hour in august $\therefore$ Approved Export meter maximum 237.66KW (Distributed Generation)

With LG modules 0 to 1829.5KWh excess energy to recover per day (228.6875KW Each hour or 76.22916 per 24h day).

Western Power

0800 096 3080 General enquires

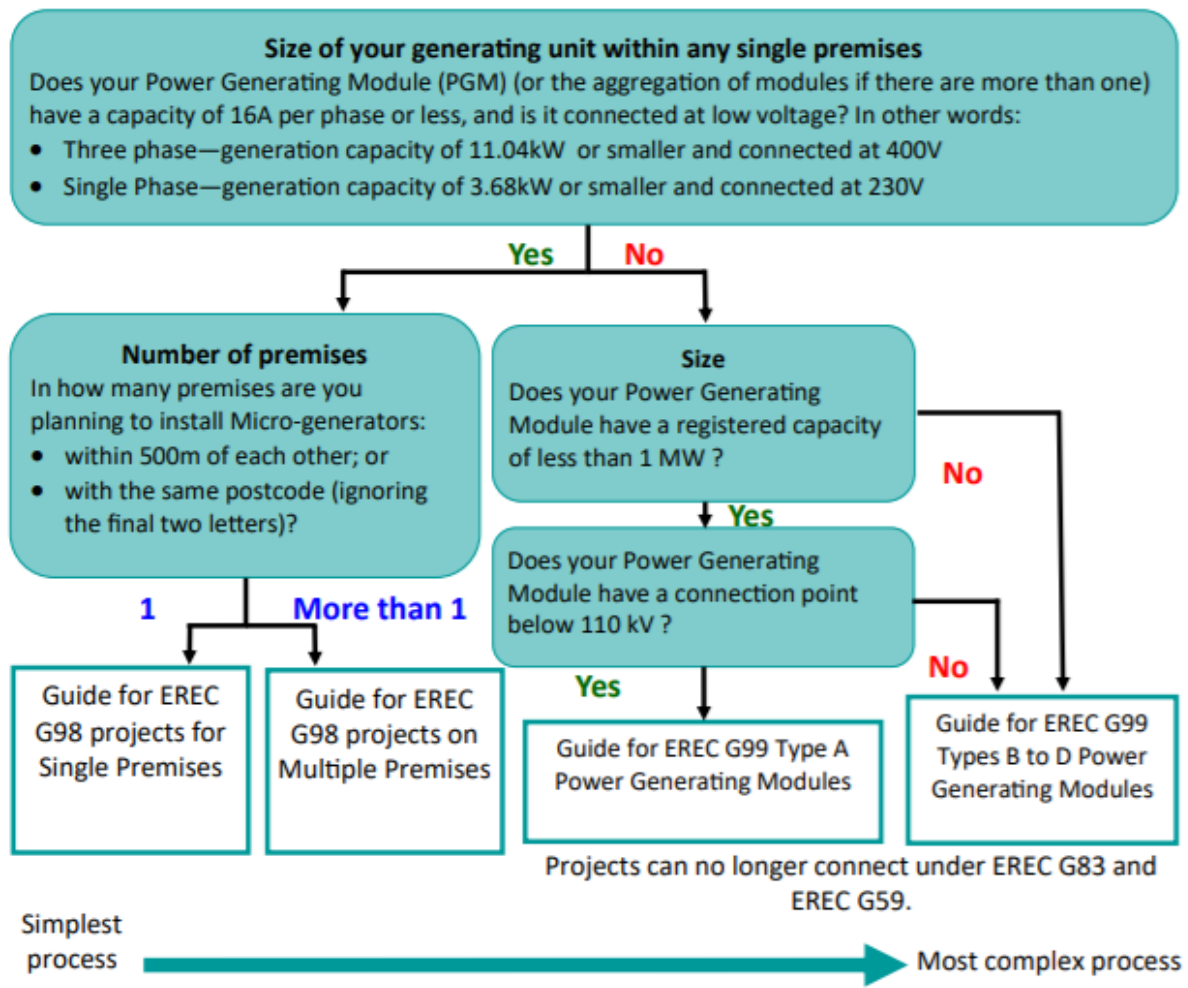
Need MPAN number from bill or meter serial number and they will start a generation limit assessment for the site with current services.

- South Wales connected generation - 02920 332843

generation.westernpower.co.uk

most feed in tariff schemes are for “Green” not Brown energy (PV), micro-combined heat and power (CHP), anaerobic digestion (AD), small-scale wind, and small-scale hydro)

<https://www.westernpower.co.uk/connections-landing/guidance-for-connecting-generation-or-energy-storage/payments-for-generated-energy>



For installations up to 50 kW, certified generation products and installers can be found on the following website: www.microgenerationcertification.org

If your Power Generating Module is less than 50 kW three-phase or 17 kW singlephase, then you can use a simplified application form. The format of the simplified application form is given in Annex A.1 of EREC G99, which is available from the Energy Network Association's website.

RfG Types A to D

The European Requirements for Generators (RfG) Code has introduced the classification of Power Generating Modules by Types. There are four types, A to D, and they relate to the registered capacity and connection voltage of the Power Generating Module. In Great Britain, the Types are:

Type A: From 0.8 kW to < 1 MW and connected at < 110 kV

Type B: From 1 MW to < 10 MW and connected at < 110 kV

Type C: From 10 MW to < 50 MW and connected at < 110 kV

Type D: ≥ 50 MW or connected at ≥ 110 kV

Note that in different European countries, the capacity and voltage thresholds may differ.

The technical requirements in RfG are less onerous on the smaller Power Generating Modules, and increase cumulatively for the larger Power Generating Modules, ie a Type B Power Generating Module must meet the requirements for Type A and Type B. Some requirements are common across all European countries. However, some requirements have country-specific parameters, which have been set by national network operators. That means that some of the parameters in Great Britain are different in Northern Ireland, and other European countries.

Apart from pumped-storage, electricity storage devices are excluded from RfG requirements—so if electricity storage devices are part of your installation and are connected via separate inverters from other generation, their capacity does not count for determining RfG Type classification.

Substation Information

Substation Name:

Westfa

This substation is within an Active Network Management Zone (ANM). If you make a connection in this zone, a cheaper connection may be available through use of Active Network Management which could avoid the need to reinforce the network. Please see [here](#).

Generation

Substation Reverse Power Capability:

12.00 MVA

Connected Generation:

10.40 MVA

Accepted not yet connected:

0.03 MVA

Substation Reverse Power Headroom:

1.57 MVA

Substation Reverse Power Limitation:

Transformer

Comments:

The Customers generation will be included in the SGT Active Network Management Scheme (ANM). The SGT ANM will automatically curtail the output of the Customers generation in order to control power flow in reverse direction through the Supergrid Transformers (SGTs) at this Grid Supply Point.

Comments:

National Grid Electricity Transmission (NGET) has instructed that WPD shall maintain a facility such that under emergency conditions on the National Electricity Transmission System (NETS), WPD shall have the ability to de-energise embedded generation ($\geq 1\text{MW}$) upon instruction from NGET.

Comments:

In order to allow WPD to contain voltage within acceptable limits at the National Electricity Transmission System (NETS) / Distribution System interface, the Customer must ensure that the generators ($\geq 1\text{MW}$) have the capability to operate between 0.95 leading and 0.95 lagging power factor. Customers will be advised of the target Power Factor within this range.

New Connections: Generation

LV Substation Point of Connection (POC)

POC Connection Type:

11kV indoor circuit breaker

POC Connection Cost:

£125,000

Average Reinforcement Cost:

£10,000

Indicative Timescale:

4-5 yrs

Major Connections (generation over 50KW)

Micro Generation (less than 50KW)

Getting Connected — Energy Storage

Storage devices for electrical energy are becoming more prevalent, and can be used as part of Distributed Generation schemes to allow generated electricity to be stored within the premises rather than exported to the distribution network.

DNOs treat storage as demand when its importing from the distribution network and generation when its exporting to the distribution network, and need to be aware of storage because of the potential impact on their networks. Therefore, storage devices need to meet the relevant connection requirements (EREC G98 or G99). Some of the technical requirements in EREC G99 do not apply to storage – these are detailed in EREC G99 Annex A.4. If you are planning to use storage in conjunction with PV (or other

technologies) to offset consumption, the total connected generation is likely to be above 16A / phase and EREC G99 applies. However, DNOs have implemented a fast track application process, for domestic scale storage. This involves submitting the G99 Form A1-2 : Application for connection of Fully Type Tested Integrated Micro Generation and Storage installations and reduces the connection time from 45 days to 10 days or less. If the storage is intended to be operated in island mode (during a power outage) the fast track process is not applicable and the standard EREC G99 process applies.

16.6 Early plan

Target 1 Anode materials= identify faulty cells in module and discharge cells

- Is this for any module or specific?
- Can partial strip down take place to test cells?
- Do I come up with cell tests?
- Discharge methods (fully past protection) or freezing?

Target 2 = remove discharged cells from module (module reduction)

- Again, is this for any module or specific?
- Is the “reduction methods” the removal of discharged cells from “module”?
- Automatic? Manual?

Target 3 = reduce cells to components

- Cell anode
- Cell cathode
- Cell electrolyte
- Cell isolating materials (sei?+)

Target 4

Target 5

- Cathode materials

Target 6

- Electrolyte materials
- Isolating materials

17 Companies that already do recycle

Umicore; Belgium smelting

Michigan technological university; Mining technique (gravity for copper and aluminium.
Froth floatation for graphite lithium and cobalt.)

Li-cycle; Canada closed loop wet chemical

Sandiego university; cathode recovery low energy

carnegie mellon university; direct cathode recycling

envirostream Australia;

faraday institution ReLiB

18 Companies that repurpose

Powervault; London (solar back up)

Hydrometallurgical recycling; discharge, shred, solvents

Ultrasonic washing

Bio leaching (hydrochloric acid, citric acid, fungi)

Bio hydrometallurgy (slow)

18.1 PPE



Serious health hazard

19 Mask

Climax - Class 1 - Full Face Silicone Full Face Mask - UNE-EN

136: 1998 - CE Marked - [CL-732]

<https://www.thesafetysupplycompany.co.uk/p/5803615/climax---class-1---full-face-silicone-full-face-mask---une-en-136-1998---ce-marked---cl-732.html>

20 filter

(EN 143 Type E Acid Filter)

Climax 757-N-B1E1 Gas Filter for the Climax 732 and 757 Face

Mask - Pair - Conforms to EN 14387:2004+A1:2008 - [CL-757N-B1E1]

<https://www.thesafetysupplycompany.co.uk/p/9230993/climax-757-n-b1e1-gas-filter-for-the-climax-732-and-757-face-mask---pair---conforms-to-en-143872004a12008---cl-757n-b1e1.html>

21 First Aid Hydrofluoric Acid Burns Cream

Calcium Gluconate Gel - For Hydrofluoric Acid Burns - 40g - [RL-C-GEL]

https://www.thesafetysupplycompany.co.uk/p/5775541/calcium-gluconate-gel---for-hydrofluoric-acid-burns---40g---rl-c-gel-.html?gclid=Cj0KCQjwoKzsBRC5ARIsAITcwXESI6yZ4j3M97B6iGwiV98SYZ22IicgZnZeHR148V9hEanKESK1gSIaAkiDEALw_wcB

22 Gloves

23 SHOWA KV660 Full PVC Coated Cut-Resistant Work Glove with Kevlar Liner, Blue, L

https://www.amazon.co.uk/Showa-Cut-Protection-Kevlar-Gloves/dp/B004L60766/ref=sr_1_11?keywords=chemical+cut+gloves&qid=1569436316&sr=8-11

23.1 Scripts

23.1.1 Case tests

```
clc
clear
close all
```

```
denall = xlsread('Denmat.xlsx', 'Denmat', 'A46:AM2941');
%% part geometry
% thickness
st = 1.6; % side in mm
ct = 3; %cap
wt = 1.6; %weld
% length
L = 46.5; % forst tests
Lv = 340; % validation
% width
wA = 25;
wB = 25.5;
wC = 25.5;
wD = 25.5;
wE = 24.5;
wF = 23.2;
wG = 22.2;
wH = 22.7;
wI = 23.5;
wJ = 24.15;
wN = 17.7;
wO = 19.1;
wP = 16;
```

```
%% side test
%forces
FA= denall(:,2);
FB= denall(:,5);
FC= denall(:,8);
FD= denall(:,11);

%displacement
dA= denall(:,3);
dB= denall(:,6);
dC= denall(:,9);
dD= denall(:,12);

%% cap test
%forces
FE= denall(:,14);
FF= denall(:,17);
FG= denall(:,20);
%displacement
dE= denall(:,15);
dF= denall(:,18);
dG= denall(:,21);

%% weld test
%force
FH= denall(:,23);
FI= denall(:,26);
FJ= denall(:,29);
%displacement
dH= denall(:,24);
dI= denall(:,27);
dJ= denall(:,30);

%% Full Case
%force
FK= denall(:,32);
FL= denall(:,35);
FM= denall(:,38);
%displacement
dK= denall(:,33);
dL= denall(:,36);
dM= denall(:,39);

%% validate side
%forces
FN = (0.5:0.5:4)';
FO = (1:3)';
FP = (0.75:0.75:3)';
% disp dti
dN = [0.07;0.15;0.23;0.31;0.4;0.49;0.59;0.7];
dO = [0.15;0.31;0.57];
dP = [0.1;0.21;0.39;0.65];
% disp denison extension
denN = [0.101;0.194;0.291;0.39;0.494;0.6;0.716;0.847];
denO = [0.194;0.42;0.695];
denP = [0.125;0.279;0.457;0.736];
% stress
```

```

sN= (FN*1e3)/((st*1e-3)*(wN*1e-3));
sO= (FO*1e3)/((st*1e-3)*(wO*1e-3));
sP= (FP*1e3)/((st*1e-3)*(wP*1e-3));
% strain
eN= (dN)/(Lv);
eO= (dO)/(Lv);
eP= (dP)/(Lv);
% E youngs
Ev(1) = (sN(7)-sN(2))/(eN(7)-eN(2));
Ev(2) = (sO(2)-sO(1))/(eO(2)-eO(1));
Ev(3) = (sP(3)-sP(1))/(eP(3)-eP(1));
%% graph mcwank
% thin side
figure ('Name','evaluate extension','NumberTitle','off');
sgtitle ('Evaluate Extension')
set(gca,'FontSize',20)

subplot (2,2,1)
plot (FN,denN)
hold on
plot (FN,dN)
hold off
legend ('DTI','Extension on Machine')
title ('Sample A')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,2)
plot (FO,denO)
hold on
plot (FO,dO)
hold off
legend ('DTI','Extension on Machine')
title ('Sample B')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,3)
plot (FP,denP)
hold on
plot (FP,dP)
hold off
legend ('DTI','Extension on Machine')
title ('Sample C')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

%% stress (pa 0r Nm^2)
sA= (FA*1e3)/((st*1e-3)*(wA*1e-3));
sB= (FB*1e3)/((st*1e-3)*(wB*1e-3));
sC= (FC*1e3)/((st*1e-3)*(wC*1e-3));

```

```

sD= (FD*1e3)/((st*1e-3)*(wD*1e-3));
sE= (FE*1e3)/((ct*1e-3)*(wE*1e-3));
sF= (FF*1e3)/((ct*1e-3)*(wF*1e-3));
sG= (FG*1e3)/((ct*1e-3)*(wG*1e-3));
%% strain (no unit)
eA= (dA)/(L);
eB= (dB)/(L);
eC= (dC)/(L);
eD= (dD)/(L);
eE= (dE)/(L);
eF= (dF)/(L);
eG= (dG)/(L);

%% youngs
% b = gradient (eB,sB)
i = find (sB>5e7);
j = find (sB>10e7);
EB = (sB(j(1))-sB(i(1)))/(eB(j(1))-eB(i(1)));
i = find (sC>5e7);
j = find (sC>10e7);
EC = (sC(j(1))-sC(i(1)))/(eC(j(1))-eC(i(1)));
i = find (sE>5e7);
j = find (sE>10e7);
EE = (sE(j(1))-sE(i(1)))/(eE(j(1))-eE(i(1)));
i = find (sG>5e7);
j = find (sG>10e7);
EG = (sG(j(1))-sG(i(1)))/(eG(j(1))-eG(i(1)));
%% graph mcwank
% thin side
figure ('Name','Thin Side Case','NumberTitle','off');
sgtitle ('Thin Side Case')

subplot (2,2,1)
plot (dA,FA)
title ('Sample A (Jaw)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,2)
plot (dB,FB)
title ('Sample B (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,3)
plot (dC,FC)
title ('Sample C (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,4)

```

```
plot (dD,FD)
title ('Sample D (Jaw)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

% thick cap
figure ('Name','Thick Cast Cap','NumberTitle','off');
sgtitle ('Thick Cast Cap')

subplot (2,2,1)
plot (dE,FE)
title ('Sample E (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,2)
plot (dF,FF)
title ('Sample F (Jaw)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,3)
plot (dG,FG)
title ('Sample G (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

%%
%Module
figure ('Name','Module','NumberTitle','off');
sgtitle ('Module')

subplot (2,1,1)
plot (dK,FK)
title ('Full Module Gimble')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

% subplot (2,2,2)
% plot (dL,FL)
% title ('Full Module Gimble')
% xlabel ('Extension (mm)')
% ylabel ('Force (KN)')
% grid on
```

```
% grid minor

subplot (2,1,2)
plot (dM,FM)
title ('Full Module Fixed')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

%%
figure ('Name','Weld','NumberTitle','off');
sgtitle ('Weld')

subplot (2,2,1)
plot (dH,FH)
title ('Sample H (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,2)
plot (dI,FI)
title ('Sample I (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,3)
plot (dJ,FJ)
title ('Sample J (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

%% wa
figure ('Name','stress strain','NumberTitle','off');
sgtitle ('stress strain')

subplot (2,2,1)
plot (eB,sB)
title ('Sample B (side)')
xlabel ('Strain')
ylabel ('Stress (N/m^2)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,2)
plot (eC,sC)
```

```
title ('Sample C (Side)')
xlabel ('Strain')
ylabel ('Stress (N/m^2)')
grid on
grid minor
set(gca, 'FontSize', 20)

subplot (2,2,3)
plot (eE, sE)
title ('Sample E (Cap)')
xlabel ('Strain')
ylabel ('Stress (N/m^2)')
grid on
grid minor
set(gca, 'FontSize', 20)

subplot (2,2,4)
plot (eG, sG)
title ('Sample G (Cap)')
xlabel ('Strain')
ylabel ('Stress (N/m^2)')
grid on
grid minor
set(gca, 'FontSize', 20)
```

23.1.2 Discharge

```
clc
clear
close all

denall = xlsread('Denmat.xlsx', 'Denmat', 'A46:AM2941');
%% part geometry
% thickness
st = 1.6; % side in mm
ct = 3; %cap
wt = 1.6; %weld
% length
L = 46.5; % forst tests
Lv = 340; % validation
% width
wA = 25;
wB = 25.5;
wC = 25.5;
wD = 25.5;
wE = 24.5;
wF = 23.2;
wG = 22.2;
wH = 22.7;
wI = 23.5;
wJ = 24.15;
wN = 17.7;
wO = 19.1;
wP = 16;

%% side test
%forces
FA= denall(:,2);
FB= denall(:,5);
```

```

FC= denall(:,8);
FD= denall(:,11);

%displacement
dA= denall(:,3);
dB= denall(:,6);
dC= denall(:,9);
dD= denall(:,12);

%% cap test
%forces
FE= denall(:,14);
FF= denall(:,17);
FG= denall(:,20);
%displacement
dE= denall(:,15);
dF= denall(:,18);
dG= denall(:,21);

%% weld test
%force
FH= denall(:,23);
FI= denall(:,26);
FJ= denall(:,29);
%displacement
dH= denall(:,24);
dI= denall(:,27);
dJ= denall(:,30);

%% Full Case
%force
FK= denall(:,32);
FL= denall(:,35);
FM= denall(:,38);
%displacement
dK= denall(:,33);
dL= denall(:,36);
dM= denall(:,39);

%% validate side
%forces
FN = (0.5:0.5:4)';
FO = (1:3)';
FP = (0.75:0.75:3)';
% disp dti
dN = [0.07;0.15;0.23;0.31;0.4;0.49;0.59;0.7];
dO = [0.15;0.31;0.57];
dP = [0.1;0.21;0.39;0.65];
% disp denison extension
denN = [0.101;0.194;0.291;0.39;0.494;0.6;0.716;0.847];
denO = [0.194;0.42;0.695];
denP = [0.125;0.279;0.457;0.736];
% stress
sN= (FN*1e3)/((st*1e-3)*(wN*1e-3));
sO= (FO*1e3)/((st*1e-3)*(wO*1e-3));
sP= (FP*1e3)/((st*1e-3)*(wP*1e-3));
% strain
eN= (dN)/(Lv);

```

```

eO= (dO)/(Lv);
eP= (dP)/(Lv);
% E youngs
Ev(1) = (sN(7)-sN(2))/(eN(7)-eN(2));
Ev(2) = (sO(2)-sO(1))/(eO(2)-eO(1));
Ev(3) = (sP(3)-sP(1))/(eP(3)-eP(1));
%% graph mcwank
% thin side
figure ('Name','evaluate extension','NumberTitle','off');
sgtitle ('Evaluate Extension')
set(gca,'FontSize',20)

subplot (2,2,1)
plot (FN,denN)
hold on
plot (FN,dN)
hold off
legend ('DTI','Extension on Machine')
title ('Sample A')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,2)
plot (FO,denO)
hold on
plot (FO,dO)
hold off
legend ('DTI','Extension on Machine')
title ('Sample B')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,3)
plot (FP,denP)
hold on
plot (FP,dP)
hold off
legend ('DTI','Extension on Machine')
title ('Sample C')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

%% stress (pa    0r Nm^2)
sA= (FA*1e3)/((st*1e-3)*(wA*1e-3));
sB= (FB*1e3)/((st*1e-3)*(wB*1e-3));
sC= (FC*1e3)/((st*1e-3)*(wC*1e-3));
sD= (FD*1e3)/((st*1e-3)*(wD*1e-3));
sE= (FE*1e3)/((ct*1e-3)*(wE*1e-3));
sF= (FF*1e3)/((ct*1e-3)*(wF*1e-3));
sG= (FG*1e3)/((ct*1e-3)*(wG*1e-3));
%% strain (no unit)

```

```

eA= (dA)/(L);
eB= (dB)/(L);
eC= (dC)/(L);
eD= (dD)/(L);
eE= (dE)/(L);
eF= (dF)/(L);
eG= (dG)/(L);

%% youngs
% b = gradient (eB,sB)
i = find (sB>5e7);
j = find (sB>10e7);
EB = (sB(j(1))-sB(i(1)))/(eB(j(1))-eB(i(1)));
i = find (sC>5e7);
j = find (sC>10e7);
EC = (sC(j(1))-sC(i(1)))/(eC(j(1))-eC(i(1)));
i = find (sE>5e7);
j = find (sE>10e7);
EE = (sE(j(1))-sE(i(1)))/(eE(j(1))-eE(i(1)));
i = find (sG>5e7);
j = find (sG>10e7);
EG = (sG(j(1))-sG(i(1)))/(eG(j(1))-eG(i(1)));
%% graph mcwank
% thin side
figure ('Name','Thin Side Case','NumberTitle','off');
sgtitle ('Thin Side Case')

subplot (2,2,1)
plot (dA,FA)
title ('Sample A (Jaw)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,2)
plot (dB,FB)
title ('Sample B (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,3)
plot (dC,FC)
title ('Sample C (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,4)
plot (dD,FD)
title ('Sample D (Jaw)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on

```

```
grid minor
set(gca,'FontSize',20)

% thick cap
figure ('Name','Thick Cast Cap','NumberTitle','off');
sgtitle ('Thick Cast Cap')

subplot (2,2,1)
plot (dE,FE)
title ('Sample E (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,2)
plot (dF,FF)
title ('Sample F (Jaw)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,3)
plot (dG,FG)
title ('Sample G (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

%%
%Module
figure ('Name','Module','NumberTitle','off');
sgtitle ('Module')

subplot (2,1,1)
plot (dK,FK)
title ('Full Module Gimble')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

% subplot (2,2,2)
% plot (dL,FL)
% title ('Full Module Gimble')
% xlabel ('Extension (mm)')
% ylabel ('Force (KN)')
% grid on
% grid minor

subplot (2,1,2)
plot (dM,FM)
```

```
title ('Full Module Fixed')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca, 'FontSize', 20)

%%
figure ('Name', 'Weld', 'NumberTitle', 'off');
sgtitle ('Weld')

subplot (2,2,1)
plot (dH, FH)
title ('Sample H (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca, 'FontSize', 20)

subplot (2,2,2)
plot (dI, FI)
title ('Sample I (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca, 'FontSize', 20)

subplot (2,2,3)
plot (dJ, FJ)
title ('Sample J (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca, 'FontSize', 20)

%% wa
figure ('Name', 'stress strain', 'NumberTitle', 'off');
sgtitle ('stress strain')

subplot (2,2,1)
plot (eB, sB)
title ('Sample B (side)')
xlabel ('Strain')
ylabel ('Stress (N/m^2)')
grid on
grid minor
set(gca, 'FontSize', 20)

subplot (2,2,2)
plot (eC, sC)
title ('Sample C (Side)')
xlabel ('Strain')
ylabel ('Stress (N/m^2)')
grid on
```

```
grid minor
set(gca,'FontSize',20)

subplot (2,2,3)
plot (eE,sE)
title ('Sample E (Cap)')
xlabel ('Strain')
ylabel ('Stress (N/m^2)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,4)
plot (eG,sG)
title ('Sample G (Cap)')
xlabel ('Strain')
ylabel ('Stress (N/m^2)')
grid on
grid minor
set(gca,'FontSize',20)
```

23.1.3 Recovery

```
clc
clear
close all

denall = xlsread('Denmat.xlsx','Denmat','A46:AM2941');
%% part geometry
% thickness
st = 1.6; % side in mm
ct = 3; %cap
wt = 1.6; %weld
% length
L = 46.5; % forst tests
Lv = 340; % validation
% width
wA = 25;
wB = 25.5;
wC = 25.5;
wD = 25.5;
wE = 24.5;
wF = 23.2;
wG = 22.2;
wH = 22.7;
wI = 23.5;
wJ = 24.15;
wN = 17.7;
wO = 19.1;
wP = 16;

%% side test
%forces
FA= denall(:,2);
FB= denall(:,5);
FC= denall(:,8);
FD= denall(:,11);
```

```

%displacement
dA= denall(:,3);
dB= denall(:,6);
dC= denall(:,9);
dD= denall(:,12);

%% cap test
%forces
FE= denall(:,14);
FF= denall(:,17);
FG= denall(:,20);
%displacement
dE= denall(:,15);
dF= denall(:,18);
dG= denall(:,21);

%% weld test
%force
FH= denall(:,23);
FI= denall(:,26);
FJ= denall(:,29);
%displacement
dH= denall(:,24);
dI= denall(:,27);
dJ= denall(:,30);

%% Full Case
%force
FK= denall(:,32);
FL= denall(:,35);
FM= denall(:,38);
%displacement
dK= denall(:,33);
dL= denall(:,36);
dM= denall(:,39);

%% validate side
%forces
FN = (0.5:0.5:4)';
FO = (1:3)';
FP = (0.75:0.75:3)';
% disp dti
dN = [0.07;0.15;0.23;0.31;0.4;0.49;0.59;0.7];
dO = [0.15;0.31;0.57];
dP = [0.1;0.21;0.39;0.65];
% disp denison extension
denN = [0.101;0.194;0.291;0.39;0.494;0.6;0.716;0.847];
denO = [0.194;0.42;0.695];
denP = [0.125;0.279;0.457;0.736];
% stress
sN= (FN*1e3)/((st*1e-3)*(wN*1e-3));
sO= (FO*1e3)/((st*1e-3)*(wO*1e-3));
sP= (FP*1e3)/((st*1e-3)*(wP*1e-3));
% strain
eN= (dN)/(Lv);
eO= (dO)/(Lv);
eP= (dP)/(Lv);
% E youngs

```

```

Ev(1) = (sN(7)-sN(2))/(eN(7)-eN(2));
Ev(2) = (sO(2)-sO(1))/(eO(2)-eO(1));
Ev(3) = (sP(3)-sP(1))/(eP(3)-eP(1));
%% graph mcwank
% thin side
figure ('Name','evaluate extension','NumberTitle','off');
sgtitle ('Evaluate Extension')
set(gca,'FontSize',20)

subplot (2,2,1)
plot (FN,denN)
hold on
plot (FN,dN)
hold off
legend ('DTI','Extension on Machine')
title ('Sample A')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,2)
plot (FO,denO)
hold on
plot (FO,dO)
hold off
legend ('DTI','Extension on Machine')
title ('Sample B')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,3)
plot (FP,denP)
hold on
plot (FP,dP)
hold off
legend ('DTI','Extension on Machine')
title ('Sample C')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

%% stress (pa    Or Nm^2)
sA= (FA*1e3)/((st*1e-3)*(wA*1e-3));
sB= (FB*1e3)/((st*1e-3)*(wB*1e-3));
sC= (FC*1e3)/((st*1e-3)*(wC*1e-3));
sD= (FD*1e3)/((st*1e-3)*(wD*1e-3));
sE= (FE*1e3)/((ct*1e-3)*(wE*1e-3));
sF= (FF*1e3)/((ct*1e-3)*(wF*1e-3));
sG= (FG*1e3)/((ct*1e-3)*(wG*1e-3));
%% strain (no unit)
eA= (dA)/(L);
eB= (dB)/(L);
eC= (dC)/(L);

```

```

eD= (dD)/(L);
eE= (dE)/(L);
eF= (dF)/(L);
eG= (dG)/(L);

%% youngs
% b = gradient (eB,sB)
i = find (sB>5e7);
j = find (sB>10e7);
EB = (sB(j(1))-sB(i(1)))/(eB(j(1))-eB(i(1)));
i = find (sC>5e7);
j = find (sC>10e7);
EC = (sC(j(1))-sC(i(1)))/(eC(j(1))-eC(i(1)));
i = find (sE>5e7);
j = find (sE>10e7);
EE = (sE(j(1))-sE(i(1)))/(eE(j(1))-eE(i(1)));
i = find (sG>5e7);
j = find (sG>10e7);
EG = (sG(j(1))-sG(i(1)))/(eG(j(1))-eG(i(1)));
%% graph mcwank
% thin side
figure ('Name','Thin Side Case','NumberTitle','off');
sgtitle ('Thin Side Case')

subplot (2,2,1)
plot (dA,FA)
title ('Sample A (Jaw)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,2)
plot (dB,FB)
title ('Sample B (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,3)
plot (dC,FC)
title ('Sample C (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,4)
plot (dD,FD)
title ('Sample D (Jaw)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

```

```
% thick cap
figure ('Name','Thick Cast Cap','NumberTitle','off');
sgtitle ('Thick Cast Cap')

subplot (2,2,1)
plot (dE,FE)
title ('Sample E (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,2)
plot (dF,FF)
title ('Sample F (Jaw)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,3)
plot (dG,FG)
title ('Sample G (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

%%
%Module
figure ('Name','Module','NumberTitle','off');
sgtitle ('Module')

subplot (2,1,1)
plot (dK,FK)
title ('Full Module Gimble')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

% subplot (2,2,2)
% plot (dL,FL)
% title ('Full Module Gimble')
% xlabel ('Extension (mm)')
% ylabel ('Force (KN)')
% grid on
% grid minor

subplot (2,1,2)
plot (dM,FM)
title ('Full Module Fixed')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
```

```
grid minor
set(gca,'FontSize',20)

%%
figure ('Name','Weld','NumberTitle','off');
sgtitle ('Weld')

subplot (2,2,1)
plot (dH,FH)
title ('Sample H (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,2)
plot (dI,FI)
title ('Sample I (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,3)
plot (dJ,FJ)
title ('Sample J (Centre)')
xlabel ('Extension (mm)')
ylabel ('Force (KN)')
grid on
grid minor
set(gca,'FontSize',20)

%% wa
figure ('Name','stress strain','NumberTitle','off');
sgtitle ('stress strain')

subplot (2,2,1)
plot (eB,sB)
title ('Sample B (side)')
xlabel ('Strain')
ylabel ('Stress (N/m^2)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,2)
plot (eC,sC)
title ('Sample C (Side)')
xlabel ('Strain')
ylabel ('Stress (N/m^2)')
grid on
grid minor
set(gca,'FontSize',20)

subplot (2,2,3)
```

```

plot (eE,sE)
title ('Sample E (Cap)')
xlabel ('Strain')
ylabel ('Stress (N/m^2)')
grid on
grid minor
set(gca,'FontSize',20)

```

```

subplot (2,2,4)
plot (eG,sG)
title ('Sample G (Cap)')
xlabel ('Strain')
ylabel ('Stress (N/m^2)')
grid on
grid minor
set(gca,'FontSize',20)

```

23.1.4 Drain App

```
classdef Discharge < matlab.apps.AppBase
```

```
% Properties that correspond to app components
```

```
properties (Access = public)
```

Discharge_fig	matlab.ui.Figure
UIAxes	matlab.ui.control.UIAxes
CellChemistryDropDownLabel	matlab.ui.control.Label
CellChemistryDropDown	matlab.ui.control.DropDown
TotalCellsEditFieldLabel	matlab.ui.control.Label
TotalCellsEditField	matlab.ui.control.NumericEditField
ModuleMaxVoltageEditFieldLabel	matlab.ui.control.Label
ModuleMaxVoltageEditField	matlab.ui.control.NumericEditField
ModuleMinVoltageLabel	matlab.ui.control.Label
ModuleMinVoltageEditField	matlab.ui.control.NumericEditField
ModuleNominalVoltageEditFieldLabel	matlab.ui.control.Label
ModuleNominalVoltageEditField	matlab.ui.control.NumericEditField
CellAhEditFieldLabel	matlab.ui.control.Label
CellAhEditField	matlab.ui.control.NumericEditField
CalculateModuleVotagesButton	matlab.ui.control.Button
StartingvoltageEditFieldLabel	matlab.ui.control.Label
StartingvoltageEditField	matlab.ui.control.NumericEditField
CellWhenergynominalEditFieldLabel	matlab.ui.control.Label
CellWhenergynominalEditField	matlab.ui.control.NumericEditField
ParallelCellsEditFieldLabel	matlab.ui.control.Label
ParallelCellsEditField	matlab.ui.control.NumericEditField
SeriesCellsEditFieldLabel	matlab.ui.control.Label
SeriesCellsEditField	matlab.ui.control.NumericEditField
LoadCurrentResistanceEditFieldLabel	matlab.ui.control.Label
LoadCurrentResistanceEditField	matlab.ui.control.NumericEditField
DischargeTimeEditFieldLabel	matlab.ui.control.Label
DischargeTimeEditField	matlab.ui.control.NumericEditField
ModulenominalAhEditFieldLabel	matlab.ui.control.Label
ModulenominalAhEditField	matlab.ui.control.NumericEditField
ModuleWhenergynominalEditFieldLabel	matlab.ui.control.Label

```

ModuleWhenergynominalEditField    matlab.ui.control.NumericEditField
DischargeLabel                    matlab.ui.control.Label
andCellLabel                      matlab.ui.control.Label
CalculatorLabel                   matlab.ui.control.Label
AmpHoursDischargedEditFieldLabel  matlab.ui.control.Label
AmpHoursDischargedEditField       matlab.ui.control.NumericEditField
AhBellow9vuseminEditFieldLabel    matlab.ui.control.Label
AhBellow9vuseminEditField        matlab.ui.control.NumericEditField
PercentAhoftotaldischargedEditFieldLabel  matlab.ui.control.Label
PercentAhoftotaldischargedEditField
matlab.ui.control.NumericEditField
PercentAhofBellow9vdischargedEditFieldLabel  matlab.ui.control.Label
PercentAhofBellow9vdischargedEditField
matlab.ui.control.NumericEditField
end

% Callbacks that handle component events
methods (Access = private)

% Button pushed function: CalculateModuleVotagesButton
function CalculateModuleVotagesButtonPushed(app, event)
    seriees_cell_no = app.SeriesCellsEditField.Value;
    Parallel_cell_no = app.ParallelCellsEditField.Value;
    if seriees_cell_no == 0
        seriees_cell_no = 1;
    end
    if Parallel_cell_no == 0
        Parallel_cell_no = 1;
    end
    R = app.CellChemistryDropDown.Value;
    if app.CellChemistryDropDown.Value == 'a'
        R = 2;
    elseif app.CellChemistryDropDown.Value == 'b'
        R = 1;
    end
    Cell = [ 58 3.6 4.2 2 812 257 ; 52.5 3.6 4.15 2.5 775 243];

    app.TotalCellsEditField.Value = Parallel_cell_no*seriees_cell_no;
    app.ModuleMaxVoltageEditField.Value = seriees_cell_no*Cell(R,3);
    app.ModuleMinVoltageEditField.Value = seriees_cell_no*Cell(R,4);
    app.ModuleNominalVoltageEditField.Value =
seriees_cell_no*Cell(R,2);
    app.CellAhEditField.Value = Cell(R,1);
    app.ModulenominalAhEditField.Value = Parallel_cell_no*Cell(R,1);
    app.CellWhenergynominalEditField.Value = Cell(R,1)*Cell(R,2);
    app.ModuleWhenergynominalEditField.Value =
Parallel_cell_no*Cell(R,1)*seriees_cell_no*Cell(R,4);

    load ('dischargedata.mat','Times','Voltage','Amps')
    Timeh = Times/3600;
    [~,idx] = min(abs(Voltage-9));

```

```

ah = trapz(Timeh,Amps);
ahnu = trapz(Timeh(1,idx:end,1),Amps(idx:end,1));

amp_f = abs(Amps);
amp_f(amp_f<2)=0.25;

resistance = Voltage./(amp_f);

yyaxis (app.UIAxes, 'left')
plot (app.UIAxes,Timeh,Voltage)
app.UIAxes.YLabel.String='Voltage and Ohms';
yyaxis (app.UIAxes, 'right')
app.UIAxes.YLabel.String='Amps';
plot (app.UIAxes,Timeh,abs(Amps))
app.UIAxes.XLabel.String='Time (hr)';
app.UIAxes.Title.String='Constant Resistance Discharge';
    axis tight
legend(app.UIAxes, 'Voltage', 'Amps')
    legend(app.UIAxes, 'Location', 'southwest')

app.StartingvoltageEditField.Value = max(Voltage);
app.DischargeTimeEditField.Value = max(Timeh);
app.LoadCurrentResistanceEditField.Value = mean(resistance);
app.AmpHoursDischargedEditField.Value = ah;
app.AhBellow9vuseminEditField.Value = ahnu;
app.PercentAhofBellow9vdischargedEditField.Value =
ahnu/(Parallel_cell_no*Cell(R,1));
app.PercentAhoftotaldischargedEditField.Value =
ah/(Parallel_cell_no*Cell(R,1));

end

% Callback function
function DischargeCalculatorButtonPushed(app, event)
%         load dischargedata
%         Timeh = Times/3600;
%         [~,idx] = min(abs(Voltage-9));
% ah = trapz(Timeh,Amps);
% ahnu = trapz(Timeh(1,idx:end,1),Amps(idx:end,1));
%
% amp_f = abs(Amps);
% amp_f(amp_f<2)=0;
%
% resistance = Voltage./(amp_f);
%
%
% yyaxis (app.UIAxes, 'left')
% plot (app.UIAxes,Timeh,Voltage)

```

```

% app.UIAxes.YLabel.String='Volatge and Ohms';
% yyaxis (app.UIAxes,'right')
% app.UIAxes.YLabel.String='Amps';
% plot (app.UIAxes,Timeh,abs(Amps))
% app.UIAxes.XLabel.String='Time (hr)';
% app.UIAxes.Title.String='Constant Resistance Discharge';
% axis tight
% legend(app.UIAxes,'Voltage','Amps')
% legend(app.UIAxes,'Location','southwest')
%
%
% app.StartingvoltageEditField.Value = max(Voltage);
% app.DischargeTimeEditField.Value = max(Timeh);
% %app.LoadCurrentResistanceEditField.Value = mean(resistance);
% app.AmpHoursDischargedEditField.Value = ah;
% app.AhBellow9vuseminEditField.Value = ahnu;
% app.PercentAhofBellow9vdischargedEditField.Value =
ahnu/Parallel_cell_no*Cell(R,1);
% app.PercentAhoftotaldischargedEditField.Value =
ah/Parallel_cell_no*Cell(R,1);
%
    end
end

% Component initialization
methods (Access = private)

% Create UIFigure and components
function createComponents(app)

% Create Discharge_fig and hide until all components are created
app.Discharge_fig = uifigure('Visible', 'off');
app.Discharge_fig.Position = [100 100 667 498];
app.Discharge_fig.Name = 'Ryan''s Discharge';

% Create UIAxes
app.UIAxes = uiaxes(app.Discharge_fig);
title(app.UIAxes, 'Title')
xlabel(app.UIAxes, 'X')
ylabel(app.UIAxes, 'Y')
app.UIAxes.Position = [232 188 420 286];

% Create CellChemistryDropDownLabel
app.CellChemistryDropDownLabel = uilabel(app.Discharge_fig);
app.CellChemistryDropDownLabel.HorizontalAlignment = 'right';
app.CellChemistryDropDownLabel.Position = [21 219 83 22];
app.CellChemistryDropDownLabel.Text = 'Cell Chemistry';

```

```
% Create CellChemistryDropDown
app.CellChemistryDropDown = uidropdown(app.Discharge_fig);
app.CellChemistryDropDown.Items = {'NMC China', 'NMC ROW'};
app.CellChemistryDropDown.ItemsData = {'a', 'b'};
app.CellChemistryDropDown.Position = [119 219 100 22];
app.CellChemistryDropDown.Value = 'b';

% Create TotalCellsEditFieldLabel
app.TotalCellsEditFieldLabel = uilabel(app.Discharge_fig);
app.TotalCellsEditFieldLabel.HorizontalAlignment = 'right';
app.TotalCellsEditFieldLabel.Position = [99 177 61 22];
app.TotalCellsEditFieldLabel.Text = 'Total Cells';

% Create TotalCellsEditField
app.TotalCellsEditField = uieditfield(app.Discharge_fig,
'numeric');
app.TotalCellsEditField.Position = [175 177 44 22];

% Create ModuleMaxVoltageEditFieldLabel
app.ModuleMaxVoltageEditFieldLabel = uilabel(app.Discharge_fig);
app.ModuleMaxVoltageEditFieldLabel.HorizontalAlignment = 'right';
app.ModuleMaxVoltageEditFieldLabel.Position = [46 156 114 22];
app.ModuleMaxVoltageEditFieldLabel.Text = 'Module Max Voltage';

% Create ModuleMaxVoltageEditField
app.ModuleMaxVoltageEditField = uieditfield(app.Discharge_fig,
'numeric');
app.ModuleMaxVoltageEditField.Position = [175 156 44 22];

% Create ModuleMinVoltageLabel
app.ModuleMinVoltageLabel = uilabel(app.Discharge_fig);
app.ModuleMinVoltageLabel.HorizontalAlignment = 'right';
app.ModuleMinVoltageLabel.Position = [33 135 127 22];
app.ModuleMinVoltageLabel.Text = 'Module Min Voltage ??';

% Create ModuleMinVoltageEditField
app.ModuleMinVoltageEditField = uieditfield(app.Discharge_fig,
'numeric');
app.ModuleMinVoltageEditField.Position = [175 135 44 22];

% Create ModuleNominalVoltageEditFieldLabel
app.ModuleNominalVoltageEditFieldLabel =
uilabel(app.Discharge_fig);
app.ModuleNominalVoltageEditFieldLabel.HorizontalAlignment =
'right';
app.ModuleNominalVoltageEditFieldLabel.Position = [25 114 135 22];
```

```

Voltage';

    app.ModuleNominalVoltageEditFieldLabel.Text = 'Module Nominal
Voltage';

    % Create ModuleNominalVoltageEditField
    app.ModuleNominalVoltageEditField = uicontrol(app.Discharge_fig,
'numeric');
    app.ModuleNominalVoltageEditField.Position = [175 114 44 22];

    % Create CellAhEditFieldLabel
    app.CellAhEditFieldLabel = uicontrol(app.Discharge_fig);
    app.CellAhEditFieldLabel.HorizontalAlignment = 'right';
    app.CellAhEditFieldLabel.Position = [113 93 47 22];
    app.CellAhEditFieldLabel.Text = 'Cell Ah ';

    % Create CellAhEditField
    app.CellAhEditField = uicontrol(app.Discharge_fig, 'numeric');
    app.CellAhEditField.Position = [175 93 44 22];

    % Create CalculateModuleVotagesButton
    app.CalculateModuleVotagesButton = uicontrol(app.Discharge_fig,
'push');
    app.CalculateModuleVotagesButton.ButtonPushedFcn =
createCallbackFcn(app, @CalculateModuleVotagesButtonPushed, true);
    app.CalculateModuleVotagesButton.Position = [60 198 159 22];
    app.CalculateModuleVotagesButton.Text = 'Calculate Module Votages
';

    % Create StartingvoltageEditFieldLabel
    app.StartingvoltageEditFieldLabel = uicontrol(app.Discharge_fig);
    app.StartingvoltageEditFieldLabel.HorizontalAlignment = 'right';
    app.StartingvoltageEditFieldLabel.Position = [397 154 89 22];
    app.StartingvoltageEditFieldLabel.Text = 'Starting voltage';

    % Create StartingvoltageEditField
    app.StartingvoltageEditField = uicontrol(app.Discharge_fig,
'numeric');
    app.StartingvoltageEditField.Position = [501 154 100 22];

    % Create CellWhenergynominalEditFieldLabel
    app.CellWhenergynominalEditFieldLabel =
uicontrol(app.Discharge_fig);
    app.CellWhenergynominalEditFieldLabel.HorizontalAlignment =
'right';
    app.CellWhenergynominalEditFieldLabel.Position = [19 51 141 22];
    app.CellWhenergynominalEditFieldLabel.Text = 'Cell Wh (energy
nominal)';

```

```
% Create CellWhenergynominalEditField
app.CellWhenergynominalEditField = uieditfield(app.Discharge_fig,
'numeric');
app.CellWhenergynominalEditField.Position = [175 51 44 22];

% Create ParallelCellsEditFieldLabel
app.ParallelCellsEditFieldLabel = uilabel(app.Discharge_fig);
app.ParallelCellsEditFieldLabel.HorizontalAlignment = 'right';
app.ParallelCellsEditFieldLabel.Position = [60 261 75 22];
app.ParallelCellsEditFieldLabel.Text = 'Parallel Cells';

% Create ParallelCellsEditField
app.ParallelCellsEditField = uieditfield(app.Discharge_fig,
'numeric');
app.ParallelCellsEditField.Position = [153 261 66 22];

% Create SeriesCellsEditFieldLabel
app.SeriesCellsEditFieldLabel = uilabel(app.Discharge_fig);
app.SeriesCellsEditFieldLabel.HorizontalAlignment = 'right';
app.SeriesCellsEditFieldLabel.Position = [60 240 70 22];
app.SeriesCellsEditFieldLabel.Text = 'Series Cells';

% Create SeriesCellsEditField
app.SeriesCellsEditField = uieditfield(app.Discharge_fig,
'numeric');
app.SeriesCellsEditField.Position = [153 240 66 22];

% Create LoadCurrentResistanceEditFieldLabel
app.LoadCurrentResistanceEditFieldLabel =
uilabel(app.Discharge_fig);
app.LoadCurrentResistanceEditFieldLabel.HorizontalAlignment =
'right';
app.LoadCurrentResistanceEditFieldLabel.Position = [344 112 142
22];
app.LoadCurrentResistanceEditFieldLabel.Text = 'Load Resistance
average';

% Create LoadCurrentResistanceEditField
app.LoadCurrentResistanceEditField =
uieditfield(app.Discharge_fig, 'numeric');
app.LoadCurrentResistanceEditField.Position = [501 112 100 22];

% Create DischargeTimeEditFieldLabel
app.DischargeTimeEditFieldLabel = uilabel(app.Discharge_fig);
app.DischargeTimeEditFieldLabel.HorizontalAlignment = 'right';
app.DischargeTimeEditFieldLabel.Position = [397 133 89 22];
app.DischargeTimeEditFieldLabel.Text = 'Discharge Time';
```

```

% Create DischargeTimeEditField
app.DischargeTimeEditField = uieditfield(app.Discharge_fig,
'numeric');
app.DischargeTimeEditField.Position = [501 133 100 22];

% Create ModulenominalAhEditFieldLabel
app.ModulenominalAhEditFieldLabel = uilabel(app.Discharge_fig);
app.ModulenominalAhEditFieldLabel.HorizontalAlignment = 'right';
app.ModulenominalAhEditFieldLabel.Position = [43 72 111 22];
app.ModulenominalAhEditFieldLabel.Text = 'Module nominal Ah ';

% Create ModulenominalAhEditField
app.ModulenominalAhEditField = uieditfield(app.Discharge_fig,
'numeric');
app.ModulenominalAhEditField.Position = [175 72 44 22];

% Create ModuleWhenergynominalEditFieldLabel
app.ModuleWhenergynominalEditFieldLabel =
uilabel(app.Discharge_fig);
app.ModuleWhenergynominalEditFieldLabel.HorizontalAlignment =
'right';
app.ModuleWhenergynominalEditFieldLabel.Position = [1 30 159 22];
app.ModuleWhenergynominalEditFieldLabel.Text = 'Module Wh (energy
nominal)';

% Create ModuleWhenergynominalEditField
app.ModuleWhenergynominalEditField =
uieditfield(app.Discharge_fig, 'numeric');
app.ModuleWhenergynominalEditField.Position = [175 30 44 22];

% Create DischargeLabel
app.DischargeLabel = uilabel(app.Discharge_fig);
app.DischargeLabel.FontSize = 30;
app.DischargeLabel.Position = [24 411 212 39];
app.DischargeLabel.Text = 'Discharge ';

% Create andCellLabel
app.andCellLabel = uilabel(app.Discharge_fig);
app.andCellLabel.FontSize = 30;
app.andCellLabel.Position = [26 375 115 37];
app.andCellLabel.Text = 'and Cell';

% Create CalculatorLabel
app.CalculatorLabel = uilabel(app.Discharge_fig);
app.CalculatorLabel.FontSize = 30;

```

```

app.CalculatorLabel.Position = [26 336 140 37];
app.CalculatorLabel.Text = 'Calculator';

% Create AmpHoursDischargedEditFieldLabel
app.AmpHoursDischargedEditFieldLabel = uilabel(app.Discharge_fig);
app.AmpHoursDischargedEditFieldLabel.HorizontalAlignment =
'right';
app.AmpHoursDischargedEditFieldLabel.Position = [356 91 130 22];
app.AmpHoursDischargedEditFieldLabel.Text = 'Amp Hours
Discharged';

% Create AmpHoursDischargedEditField
app.AmpHoursDischargedEditField = uieditfield(app.Discharge_fig,
'numeric');
app.AmpHoursDischargedEditField.Position = [501 91 100 22];

% Create AhBellow9vuseminEditFieldLabel
app.AhBellow9vuseminEditFieldLabel = uilabel(app.Discharge_fig);
app.AhBellow9vuseminEditFieldLabel.HorizontalAlignment = 'right';
app.AhBellow9vuseminEditFieldLabel.Position = [358 70 128 22];
app.AhBellow9vuseminEditFieldLabel.Text = 'Ah Bellow 9v (use
min)';

% Create AhBellow9vuseminEditField
app.AhBellow9vuseminEditField = uieditfield(app.Discharge_fig,
'numeric');
app.AhBellow9vuseminEditField.Position = [501 70 100 22];

% Create PercentAhoftotaldischargedEditFieldLabel
app.PercentAhoftotaldischargedEditFieldLabel =
uilabel(app.Discharge_fig);
app.PercentAhoftotaldischargedEditFieldLabel.HorizontalAlignment =
'right';
app.PercentAhoftotaldischargedEditFieldLabel.Position = [320 28
166 22];
app.PercentAhoftotaldischargedEditFieldLabel.Text = 'Percent Ah of
total discharged';

% Create PercentAhoftotaldischargedEditField
app.PercentAhoftotaldischargedEditField =
uieditfield(app.Discharge_fig, 'numeric');
app.PercentAhoftotaldischargedEditField.Position = [501 28 100
22];

% Create PercentAhofBellow9vdischargedEditFieldLabel
app.PercentAhofBellow9vdischargedEditFieldLabel =
uilabel(app.Discharge_fig);

```

```
app.PercentAhofBellow9vdischargedEditFieldLabel.HorizontalAlignment = 'right';
    app.PercentAhofBellow9vdischargedEditFieldLabel.Position = [290 49
196 22];
    app.PercentAhofBellow9vdischargedEditFieldLabel.Text = 'Percent Ah
of Bellow 9v discharged';

    % Create PercentAhofBellow9vdischargedEditField
    app.PercentAhofBellow9vdischargedEditField =
uieditfield(app.Discharge_fig, 'numeric');
    app.PercentAhofBellow9vdischargedEditField.Position = [501 49 100
22];

    % Show the figure after all components are created
    app.Discharge_fig.Visible = 'on';
end
end

% App creation and deletion
methods (Access = public)

    % Construct app
    function app = Discharge

        % Create UIFigure and components
        createComponents(app)

        % Register the app with App Designer
        registerApp(app, app.Discharge_fig)

        if nargin == 0
            clear app
        end
    end

    % Code that executes before app deletion
    function delete(app)

        % Delete UIFigure when app is deleted
        delete(app.Discharge_fig)
    end
end
end
```