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Second Life Batteries in a Mobile Charging Station: Experimental Performance Assessment

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ABSTRACT

Lithium-ion batteries are playing an increasingly important role in the decarbonization of our planet. Despite their key roles in electromobility and renewable energies growth, their environmental impact has to be considered and minimized. Circular economy and open data are two pathways that may help in this matter. In this article, the results of a characterization test over a second life high capacity lithium-ion cell are shared. Readers shall use the test procedure as a reference test to characterize batteries. Furthermore, the results dataset may be exploited for model fitting or validation.

Data repository described	Software used for data processing	Publication using the data repository
Dataverse repository	DATES	Hassini, Marwan & al., "Second Life Batteries in a Mobile Charging Station: Model Based Performance Assessment", EVS35, 2022

Background & Summary

Electrified vehicles and renewable energies are currently seen as interesting options to reduce greenhouse gas emissions[1]. Lithium-ion batteries are the key energy storage element necessary to develop these technologies. In order to maximize the environmental benefits of electromobility and renewable energies, it is paramount to reduce as much as possible the environmental impact of batteries.

The potentiality to reduce the pollution caused by experimental testing is among the numerous benefits of an open data approach. Economical and scientific benefits of sharing data have also been identified in several studies [2, 3, 4]. In a review article, Dos Reis et al. described the lithium-ion batteries publicly available datasets [5]. Authors have identified two gaps in the public datasets. First, a limited amount of data test are available for prismatic cells. To date, only two datasets have been shared for prismatic cells [6, 7]. Regarding second life cells, Von Hohendorff Seger and al. and Chung have shared the two first public dataset [8, 9]. The limited number of repositories shared may be explained by experimental test duration and cost as well as the origin of the funding. Due to economic considerations, private research remain reluctant to share their research data. Consequently it is the role of public research to improve scientific knowledge through data sharing.

This datapaper describes a reference performance test conducted on a second life lithium-ion cell. The shared test procedures aims to evaluate in detail the behavior of a battery. It may be used to periodically assess the evolution of parameters as capacity or resistance in an ageing campaign or to fit the parameters of a battery model. In this work, the test is used to evaluate the performance of a second life SAMSUNG SDI 94Ah cell. This dataset is the first one to share data from a test realized on a prismatic cell with a capacity over 10Ah. This is also the first study sharing data about second life batteries extracted from real electric vehicles.

Methods

A second life SAMSUNG SDI 94Ah cell have been tested in this campaign. This high energy lithium-ion cell has an approximate energy density of about 165 Wh/kg. Cell main characteristics have been collected from existing literature [10, 11, 12, 13, 14] and are synthetized in the table 1.

Table 1. Samsung SDI 94Ah main characteristics

Characteristics	Values
Geometry	Prismatic
Size L×W×H [mm]	173×125×45
Weight[kg]	2.06
Nominal capacity C_n [Ah]	94
Positive electrode chemistry	NMC 1:1:1
Negative electrode chemistry	Graphite
Specific energy [Wh/kg]	165
Operating temperature [°C]	[-40;60]
Nominale voltage U_n [V]	3,68
Maximal voltage U_{max} [V]	4,15
Minimal voltage U_{min} [V]	2,7

Experimental setup

Battery cycler

A Bitrode Battery Testing System was used for cycling experiments. Characteristics of this cycler are summarized in table 2.

Table 2. Bitrode cycler characteristics

Characteristics	Values
Reference	FTV2-250-60
Maximal voltage U_{max} [V]	60
Maximal current I_{max} [A]	250
Maximal power P_{max} [W]	15000
Circuits	2
Voltage resolution [mV]	±10
Current resolution [mA]	±10
Data Sampling Rate [ms]	10
Auxiliary voltages inputs	12
Auxiliary circuits voltage resolution [mV]	1
Voltage range [V]	[0-10]
Auxiliary temperature inputs	12
Thermocouples types	J
Temperature resolution [°C]	±0.5
Temperature range[°C]	[0-200]
Data Sampling Rate [ms]	100
Output files extension	*.mdb, *.csv

Climatic chambers

The cell were cycled at a monitored temperature in a Vötsch VT 3050 climatic chambers. Main characteristics of this chamber are summarized in table 3.

Table 3. Vötsch VT 3050 climatic chamber characteristics

Volume [L]	500
Internal dimensions LxWxH [mm]	710 x 1250 x 590
Minimal temperature T_{min} [°C]	-30
Maximal temperature T_{max} [°C]	100
Temperature accuracy [K]	± 0.5

Cell characterization test

Campaign goals

A SAMSUNG SDI 94Ah cell have been tested in the campaign. Experiments aim to determine second life cell characteristics at 0, 25 and 40°C.

Characterisation test

The characterisation test is constituted of six steps presented in the table 4

Table 4. Characterisation test

Step	Test	Estimated duration [h]
1	Experimental temperature set	4
2	Capacity test	14
3	Impedance test	7,5
4	Pseudo OCV test	42
5	WLTC cycles	12
6	Mobile charging station cycles	12

Step 1 is a rest step where experimental temperature is set. Step 2 is a capacity test, this measurement enables the models to estimate accurately the state of charge of the cell. Step 3 is an impedance measurement at different state of charge and current levels. This test enables the identification of the model impedance parameters responsible for the accurate estimation of the voltage dynamic. Step 4 is used to measure the open circuit voltage of the cell. Finally, step 5 and 6 are the validation cycles. They are used to assess the models accuracy respectively for electric vehicles and mobile charging station usages.

Capacity test

Table 5. Capacity measure test procedure

Step	Test type	Key parameters	Description
1	Discharge in CC mode	$I_{cc} = 1C = 94A$	Voltage is set to U_{min}
2	Discharge in CV mode	$U_{thres} = U_{min} = 2,7V, I_{cv} = C/20 = 4.7A$	Voltage is set to U_{min}
3	Rest	$t_{rest} = 5mn$	Rest for five minutes
4	Charge in CC mode	$I_{cc} = 1C = 94A$	Full charge at 1C
5	Charge in CV mode	$U_{thres} = U_{max} = 4,15V, I_{cv} = C/20 = 4.7A$	Voltage is set to U_{max}
6	Rest	$t_{rest} = 1h$	Rest for one hour
7	Discharge in CC mode	$I_{cc} = 1C = 94A$	Full discharge at 1C
8	Discharge in CV mode	$U_{thres} = U_{min} = 2,7V, I_{cv} = C/20 = 4.7A$	Voltage is set to U_{min}
9	Rest	$t_{rest} = 1h$	Rest for one hour

Impedance test

The impedance test consist in a serie of current pulses at different rates. The profile shown in figure 1 is done at SoC 10, 20, 30, 40, 50, 60, 70, 80 and 90%.

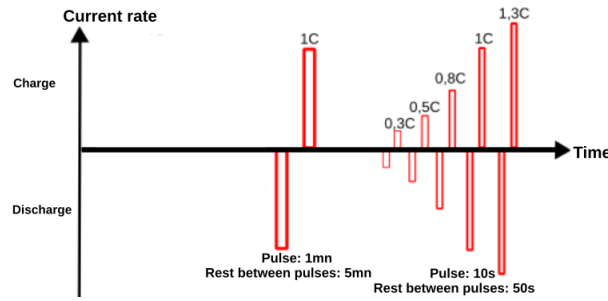


Figure 1. Current-rate versus time

Pseudo OCV test

Table 6. Low current measure

Step	Test type	Key parameters	Description
1	Rest	$t_{rest} = 5mn$	Rest for five minutes
2	Charge in CC mode	$I_{cc} = 1C = 94A$	Full charge at 1C
3	Charge in CV mode	$U_{thres} = U_{max} = 4,15V, I_{cv} = C/20 = 4.7A$	Voltage is set to U_{max}
4	Rest	$t_{rest} = 1h$	Rest for one hour
5	Discharge in CC mode	$I_{cc} = C/20 = 4.7A$	Full low current discharge
6	Rest	$t_{rest} = 1h$	Rest for one hour
7	Charge in CC mode	$I_{cc} = C/20 = 4.7A$	Full low current charge

WLTC profile

A Worldwide harmonized Light vehicles Test Cycles (WLTC) profile have been used to validate the parameters of two battery electric models measured thanks to the previous steps. This real usage profiles have been provided by the company Mob-Energy.

Table 7. Worldwide harmonized Light vehicles Test Cycles

Step	Test type	Key parameters	Description
1	Rest	$t_{rest} = 30mn$	Rest for 30mn
2	WLTC profile		WLTC profile
3	Rest	$t_{rest} = 30mn$	Rest for 30mn
4	WLTC profile		WLTC profile
5	Charge in CC mode	$I_{cc} = 1C = 94A$	Full charge at 1C
6	Charge in CV mode	$U_{thres} = U_{max} = 4,15V, I_{cv} = C/20 = 4.7A$	Voltage is set to U_{max}

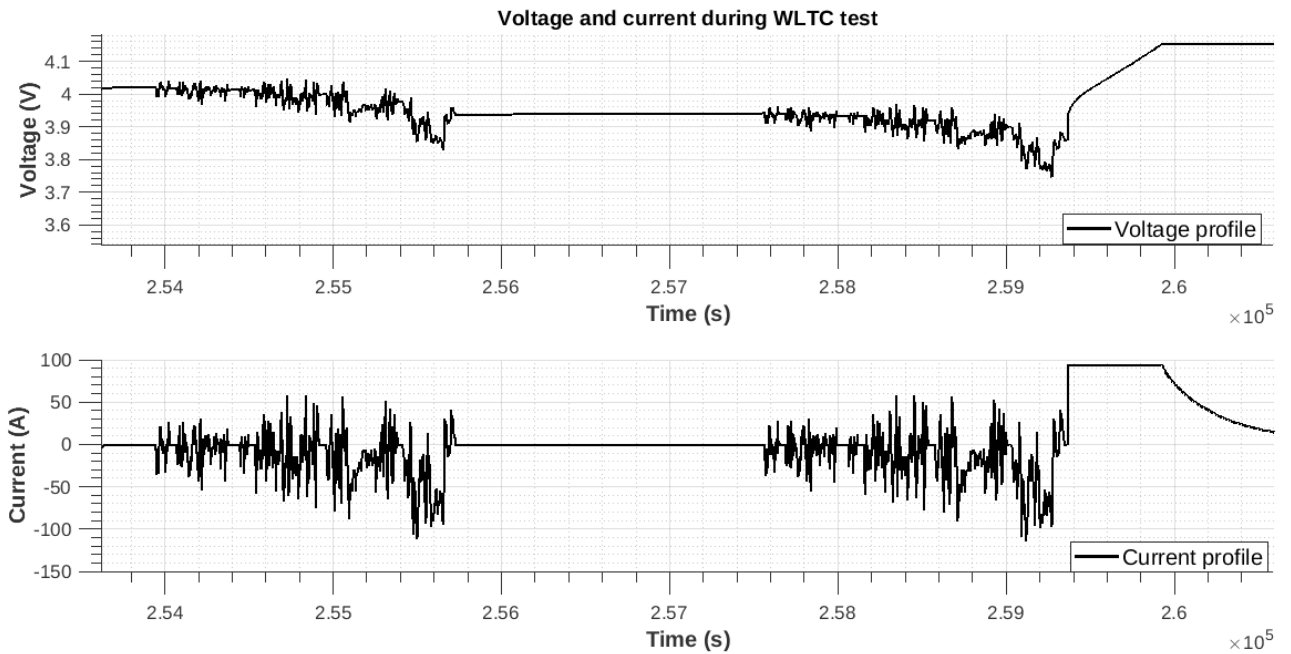


Figure 2. Voltage and current versus time during the WLTC test profile

Mobile charging station cycles

A mobile charging station's usage profile have been used to compare the capabilities of two electric models to emulate the voltage response of the reused batteries. The profile and the modeling are extensively described in a publication by Hassini and al.[15]. This real usage profiles have been provided by the company Mob-Energy.

Table 8. Mobile charging station cycles

Step	Test type	Key parameters	Description
1	Discharge in CP mode	$P_{const} = 0.4W$	Low power discharge for robot displacement
2	Discharge in CP mode	$P_{const} = 625$	Discharge of the robot to charge a vehicle
3	Discharge in CP mode	$P_{const} = 0.4W$	Low power discharge for robot displacement
4	Charge in CP mode	$P_{const} = 625$	Robot charge
5	Rest	$t_{rest} = 1h$	Rest for one hour every twelve hours
6	Charge in CC mode	$I_{const} = C/20 = 4.7A$	Full low current charge
7	Loop		Back to step 1

Data Records

Each file exhibits a characterization test profile. A unique code is used to mark the repurposed battery cell. It is composed of the prefix BUGE, which stands for Battery tested in University Gustave-Eiffel, and a 3-digit number. Data files are also named with a code. As shown in Figure 3, the code is composed of the test date and time, followed by the cell identifier and type, and finally the test temperature and the test name.

20210706_1550_BUGE324_SAMSUNGSDI94Ah_T25_connaissance

(1) (2) (3) (4) (5) (6)

(1) **Date** : The starting date of the test in a "YYYYMMDD" format
(2) **Hour** : The starting hour of the test in a "HHMM" format
(3) **Cell identifier** : The unique cell identifier in a "BUGEXXX" format
(4) **Cell type** : The cell type in a "CONSTRUCTORCAPACITY" format
(5) **Temperature** : The test temperature, in °C, controlled by a climatic chamber
(6) **Test name** : The test name

Figure 3. Test name explanations

Data files are .csv files. They are composed of 49 columns described in table 9

Table 9. Description of the data files content

Column number	Column name	Unit	Description
1	Total Time	s	Total operating time of the measurement
2	Cycle		Cycle number
3-5	Loop Counter #1-#3		Loop number
6	Step		Step number
7	Step Time	s	Operating time of the step
8	Current	A	Measured current of the channel
9	Voltage	V	Measured voltage of the channel
10	Power	W	Calculated power of the channel
11	Instantaneous Amps	A	Measured instantaneous current of the channel
12	Instantaneous Volts	V	Measured instantaneous voltage of the channel
13	Instantaneous Watts	W	Calculated instantaneous power of the channel
14	Amp-Hours	AH	Ampere-hours charged or discharged during the step
15	Watt-Hours	WH	Watt-hours charged or discharged during the step
16	Amp Hours Charge	AH	Ampere-hours charged during the step
17	Amp Hours Discharge	AH	Ampere-hours discharged during the step
18	Watt Hours Charge	WH	Watt-hours charged during the step
19	Watt Hours Discharge	WH	Watt-hours discharged during the step
20-25	Cell Voltage A1-6	V	Measured voltage of the cells
26-31	Temperature A1-6	°C	Measured temperature of the cell
32-33	Digital Input A1-2		Digital input
34-35	Digital Output A1-2		Digital output
36-47	Unassigned A1-12		Unassigned measurement channels
48	Mode		Test mode : Rest or Discharge or Charge
49	Data Acquisition Flag		Acquisition flag

Data quality control

Data quality control is ensured by realizing equipment calibration test before each test campaign. The calibration procedure have been defined by the battery cyclers manufacturer. Test reproducibility have also been checked. Table 10 presents the reproducibility test.

The test consists in comparing the voltage response of a cell during two distinct pulses waves. A rest of 24 hours is added during two waves to ensure that the cell polarization plays a limited role in the second wave voltage response.

Table 10. Reproducibility test procedure

Step	Test type	Key parameters	Description
1	Charge in CC mode	$I_{cc} = 1C = 94A$	Full charge at 1C
2	Charge in CV mode	$U_{thres} = U_{max} = 4,15V, I_{cv} = C/20 = 4.7A$	Voltage is set to U_{max}
3	Rest	$t_{rest} = 1h$	Rest for one hour
4	Discharge in CC mode	$I_{cc} = 1C = 94A, \Delta Q = 47Ah$	Discharge until SoC 70%
5	Rest	$t_{rest} = 1h$	Rest for one hour
6	5 10s-charge pulses and 5 10s-discharge pulse	$I_{cc} = 1C = 94A, t_{rest} = 10s$	10s rest between pulses
7	Rest	$t_{rest} = 24h$	Rest for 24 hours
8	5 10s-charge pulses and 5 10s-discharge pulse	$I_{cc} = 1C = 94A, t_{rest} = 10s$	10s rest between pulses

The maximal difference between the two pulses waves is of 6mV i.e. 0.1% of difference.

Usage Notes

The test procedures have been designed for general-propose usage, i.e., the procedures could be used to test any types of secondary batteries. The profile datasets provided in this work can be used in the model-based engineering of repurposed battery cells: either to fit the variables of an empirical model or to validate the results of a theoretical model.

Code availability

The datasets as reported are generated from experiments and are not relevant to any computer codes. The tool DATTES have been used to analyze and visualize the data [16, 15].

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Author contributions statement

Marwan Hassini, Eduardo Redondo-Iglesias and Pascal Venet conceived the experiment,
Marwan Hassini and Eduardo Redondo performed the cycler calibration ,
Marwan Hassini, Sylvain Gillet and Younes Zitouni set up the experiment ,
Marwan Hassini conducted the experiment and extracted the data

Competing interests

Authors declare no competing interests.

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