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At the end of the first use of batteries in industrial electric vehicles (EV), the remaining capacity is expected to be around 80-70% of its initial capacity. Therefore, autonomy becomes insufficient for the original application, although these batteries could be reused for less demanding applications. The management of recycling is the responsibility of the manufacturer, and its cost is substantial for lithium-ion and in particular for lithium iron phosphate (LFP) batteries. Indeed, second life applications for lithium-ion batteries are an opportunity for the industry to postpone recycling costs, to improve lithium-ion batteries' economic value, and to reduce environmental impact.

Capacity and power limitations need to be predictable to meet required specifications throughout the second life. The purpose of this work is to identify the necessary parameters to sort battery modules in view of a second life application. To this aim, it is necessary to assess capacity decrease, resistance increase, and other events in the whole lifetime of the battery in order to allow second-life-battery manufacturers to certify that any battery pack it sells can fulfil second life requirements. The sorting process is considered at the module level because cells are assembled with the Battery Management System (BMS) and this helps modularity in reassembly for a second use unlike a battery pack. Moreover, the sorting process at the module level is expected to be faster, cheaper and easier than at the single cell level.

This work presents an aging study that intends to continue cell aging over the end of the first life. In this context, changing behaviour or unexpected events may appear: there is no certainty that cell aging will follow the same trend during the second life. The test conditions are determined according to different possible uses of industrial EV: medium or fast charge and discharge current, or high depth of discharge. Those different parameters of use are suspected to imply a sudden shift in cell aging: acceleration of capacity fade or resistance increase. By the way, some conditions can improve battery aging. Loss of lithium inventory is commonly reported in the literature as the main aging cause in first life, but loss of active material may accelerate cell aging. The predictability of those aging process is required to set a sorting process for lithium-ion batteries in order to guarantee their use in second life. This work aims at shedding light on harmful phenomena in some normal battery use, and collect data related to their appearance. In a long-term research, this experiment data will establish a diagnosis model to estimate remaining cell capacity and a specific aging process that may lead to sudden capacity fade. Then, the prognosis of the remaining useful life will decide potential reuse in a second life application.

Cell reference	DoD (%)	Charge type	Charge cut-off voltage	Charge C-rate	Discharge condition
prismatic cell 1	70	CC	3.65V	C/3	WLTP
prismatic cell 2	70	CC-CV	3.65V	C/3	WLTP
prismatic cell 3	70	CC-CV	3.55V	C/3	WLTP
18650 cells 4, 5	70	CC	3.65V	C/3	WLTP
18650 cells 6, 7, 8	100	CC	3.65V	C/3	WLTP
18650 cells 9, 10, 11	70	CC-CV	3.55V	C/3	WLTP
18650 cells 12, 13, 14	70	CC-CV	3.65V	2C	WLTP
18650 cells 15, 16, 17	70	CC-CV	3.55V	2C	WLTP
18650 cells 18, 19, 20	70	CC-CV	3.65V	2C	CC (2C)

Table 1. Aging conditions for each cell.

Tests are being carried out in two laboratories with four test benches on new industrial cells. Three LFP industrial-electric-vehicle 72Ah high capacity prismatic cells and twenty 18650 1.1Ah cells are cyclied on different test benches. All experiments are conducted under accelerated aging at a temperature of 50°C. An electric-vehicle-type discharged profile is calculated from the Worldwide harmonized Light vehicles Test Procedures (WLTP) standard. The cycle is used to approximate a typical operation of an electric vehicle during the aging study, with a C-rate peak of 2.7C in discharge and regenerative mode. The WLTP average discharge C-rate is C/3. Table 1 summarizes aging conditions for all 23 cells. The variations depend on Depth of Discharge (DoD), charge type, Charge cut-off voltage, Charge C-rate, or discharge scenario. The change in aging rate is reported as being due to a change in aging mode. For each cell, a characterization procedure is carried out on fresh cells and every 100 cycles at 50°C. Then, the characterization procedure is repeated every 100 aging cycles to follow parameters evolution. The characterization process consists of two tests: a C/3 CCCV charge and discharge from 0 to 100% State of Charge (SoC), and a C/25 charge and discharge for pseudo-open circuit voltage measurement. The first test allow calculating the battery's remaining capacity, and the second one electrodes capacity.

Born in 1995 in France, William Wheeler gets his engineering degree in mechatronics from Université de Technologie de Compiègne in 2018. Its experimental project on the topic of electric vehicles is a stepping stone to begin a Ph.D. thesis in the field of electric vehicles batteries. He currently works at the University Claude Bernard Lyon 1 and EVE System. He focuses his research on electric vehicles batteries, aging study and reuse in a second life.

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