An Informative Lithium-Ion Battery Datasheet

Subjects: Others

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Lithium-ion battery datasheets, also known as specification sheets, are documents that battery manufacturers provide to define the battery's function, operational limit, performance, reliability, safety, cautions, prohibitions, and warranty. A datasheet lists information about the product for both informational and advertising purposes. Product manufacturers and customers rely on the datasheets for battery selection and battery management.

Keywords: lithium-ion batteries ; datasheets ; specifications ; battery manufacturers ; end-users

1. Introduction

Commercial lithium-ion batteries have been the dominant power supply for today's consumer electronics and high-power and energy mobile systems [1][2]. A technical specification sheet (datasheet) is a document that prescribes technical requirements to be fulfilled by a product, process, or service [3], is needed to choose and use a lithium-ion battery. A datasheet lists information about the product for both informational and advertising purposes [4]. Datasheets typically define the basic capabilities and performance characteristics, including product composition, methods of use, operating requirements, common applications, and product warnings.

Customers use lithium-ion battery datasheets to select the most appropriate battery for an application; these datasheets also guide product manufacturers to develop battery management systems for enhanced performance, reliability, and safety. A confusing or misleading term describing these performance parameters will affect a proper evaluation of the batteries and datasheet validation and may cause legal issues between customers and battery manufacturers. For example, a capacity term whose measurement condition is not explicitly listed can make the capacity warranty equivocal. Academia also test commercial lithium-ion batteries per the specifications to analyze and model degradation, failure, and protection mechanisms. Any inconsistencies can lead to studies using these batteries being incomplete, invalid, and not ready to be implemented for real-world applications. To date, however, there has been no dedicated review research conducted to investigate various problems in lithium-ion battery datasheets, based on the results of thorough literature research in the major academic publishers (IEEE, Elsevier, Wiley, MDPI, Springer, etc.) and Google scholar search with keywords such as "battery" and "datasheet" or "specification") [5][6][7][8][9][10][11]. This work is a first step toward filling this void by recommending improvements to the battery manufacturers.

This paper is motivated by the difficulty of using battery datasheets to compare suppliers, conduct battery tests, and design products that require batteries. The information provided in the datasheet is insufficient for the end-users due to issues including discrepancies for the same term such as using one voltage reading to specify the capacity but another to specify the cycle life, lack of critical parameters such as the operating current limits, and ambiguity such as specifying a term's value without mentioning the measurement conditions.

Recommendations are provided for battery manufacturers to develop an informative datasheet with clearly and completely defined items. An informative datasheet will make it easier for users to correctly compare suppliers' performance, evaluate the lifetime, and develop battery management systems with the appropriate voltage, current, and temperature limits.

2. Electrical Performance and Operating Limits

IEC ref 482-03-15 [3] defines the rated capacity as the capacity value of a battery determined under specified operating conditions and declared by the manufacturer. ANSI C18.2M [12] describes the rated capacity as the quantity of electricity declared by the manufacturer which a single cell or battery can deliver during a 5 h period when charging, storing, and discharge under the conditions specified in the ANSI standard in which the battery datasheets determine the cut-off voltage values. ISO 12405-4 describes the rated capacity [13] as the supplier's specification of the total number of ampere-hours that can be withdrawn from a fully charged battery pack or system for a specified set of test conditions, such as discharge rate, temperature, and discharge cut-off voltage.

Battery manufacturers should recommend charging and discharging C-rates for different temperature ranges, considering the adverse effect of increasing C-rate on battery lifetime due to mechanical stress and side-electrochemical reactions such as lithium plating and gas generation. When specifying the maximum discharge current/C-rate, the datasheet should provide the values for continuous discharge rate, pulse discharge rate with pulse length, the applied state of charge (SOC), and temperature range, such that users know the conditions they can use the battery up to the maximum discharge current.

Increased impedance/resistance can cause the battery terminal voltage to reach the discharge cut-off voltage and terminate the battery's discharge operation, thus decreasing the battery's power capability and deliverable capacity. In addition to the measurement temperature and battery SOC for the resistance/impedance values, battery datasheets should specify the measurement frequency for the impedance values. A comparison of different methods to measure the internal resistance and impedance can be found in [14].

Specific energy, also called gravimetric energy density, is the energy per unit mass stored in a lithium-ion battery/cell. Specific power is the power per unit mass provided by a lithium-ion battery/cell, changing with battery SOC and operating conditions. The specific energy and power are useful in comparing the cost per unit of energy or power among different batteries.

3. Reliability and Recommendations for Storage

The maximum amount of charge that a battery can deliver decreases with usage (cycle life through charge-discharge cycles) and storage (calendar life), known as capacity fade. A lithium-ion battery reaches the end of life when its capacity no longer meets the mission's requirement, described by the end-of-life (EOL) threshold that is predetermined for the mission. The EOL threshold is application dependent. There is also a required number of cycles or time (lifetime requirement) for each mission. That is, the battery capacity should not drop below the EOL threshold until the required lifetime. Lithium-ion batteries with unsatisfactory lifetimes can significantly reduce customer satisfaction and make products inefficient to use in such applications. Thus, the cycle life and storage life are specified in the datasheets.

Table 1 summarizes the cycle life parameters in the 25 datasheets in which the cycle life is specified for as low as 200 cycles and as high as 15,000 cycles. The cycling characteristics are usually in the form of plots (capacity vs. cycles) or the capacity retention value after being used for a certain number of cycles in which lithium-ion batteries are cycled at certain environmental and loading conditions for a specific number of cycles. Most of the 25 datasheets provide the cycling characteristics for one testing condition, whereas the A123 ANE26650m1-B datasheet provides the plots for multiple testing conditions.

Table 1. Cycle life characteristics.

Manufacturer	Model	Cycle Life
Panasonic	NCR18650PF	The capacity fade curve for 500 cycles
Panasonic	NCR18650B [15]	The capacity fade curve for 500 cycles
Panasonic	NCR18650BD	The capacity fade curve for 500 cycles
Panasonic	NCR18650BF	The capacity fade curve for 300 cycles
Panasonic	UR18650GA	The capacity fade curve for 500 cycles
Panasonic	UR18650ZY	Discharge time >38 min. at standard discharge conditions after 300 cycles
Panasonic	UR1865ZM2	The capacity fade curve for 1000 cycles
Samsung	ICR18650-26J	≥1785 mAh (70%) after 300 cycles
Samsung	INR21700-50E	≥3802 mAh (80%) after 500 cycles
Samsung	NR18650-15Q	≥870 mAh (60%) after 250 cycles
LG Chem	18650HE2	≥60% after 300 cycles at 10 A discharge or after 200 cycles at 20 A discharge
LG Chem	ICR18650MF1	≥70% after 500 cycles
LG Chem	INR18650 B4	≥80% after 300 cycles
A123	AMP20m1HD-A	The capacity fade curve for 3200 cycles
A123	ANR26650m1-B	The capacity fade curves for three conditions up to 1450 cycles
ATL	902738	—
Routejade	SLPB8043128H	≥2560 mAh after 1000 cycles
Routejade	SLPB526495	≥2640 mAh after 1000 cycles
EEMB	LIR18650	≥2050 mAh after 300 cycles

Manufacturer	Model	Cycle Life
EEMB	LIR1632	≥80% after 500 cycles
GMB	GMB043450S	≥70% after 500 cycles
VPW	580013	≥80% after 2000 cycles at 25 °C, or after 1200 cycles at 45 °C
VPW	580049	≥80% after 200 cycles
Toshiba	Toshiba-LTO-20AH	The capacity fade curve at 3C, 25 °C up to 15,000 cycles
Johnson Controls-SAFT	MP 174865 xlr	The capacity fade curve at C/2, 20 °C up to 950 cycles

— This term is not mentioned.

IEC ref 482-03-47 [3] defines storage life (shelf life) as the duration, under specific conditions, at the end of which a battery has retained the ability to perform a specified function. As shown in the third column in **Table 2** , out of the 25 datasheets, 21 specify the recommended storage temperature range (ATL, VPW, and Toshiba battery types do not provide information); however, the datasheets do not explain the implications for the storage time associated with each temperature range. For example, the statement "−20–50 °C, less than 1 month" does not reveal the amount of charge and capacity left after the battery is stored for a month at 50 °C.

Table 2. Storage life characteristics.

Manufacturer	Model	Storage Temperature (°C)	Charge Retention	Capacity Retention
Panasonic	NCR18650PF	−20–50	—	—
Panasonic	NCR18650B [15]	−20–50	—	—
Panasonic	NCR18650BD	−20–50	—	—
Panasonic	NCR18650BF	−20–50	—	—
Panasonic	UR18650GA	−20–50	—	—
Panasonic	UR18650ZY	−20–50, less than 1 month −20–40, less than 3 months −20–20, less than 1 year	Discharge time > 30 min (25 °C) after 20 days at 60 °C, 100% SOC	Discharge time > 40 min (25 °C) after 20 days at 60 °C, 100% SOC and being fully charged at 25 °C
Panasonic	UR1865ZM2	20–50, less than 1 month −20–40, less than 3 months −20–20, less than 1 year	—	—
Samsung	ICR18650-26J	−20–60, 1 month −20–45, 3 months −20–23, 1 year	Charge ≥ 2040 mAh (80%) after 30 days at 23 °C, 100% SOC	—
Samsung	INR21700-50E	−20–60, 1 month −20–45, 3 months −20–23, 1 year	Charge ≥ 2040 mAh (80%) after 30 days at 60 °C, 100% SOC	—
Samsung	NR18650-15Q	45–60, 1 month 20–45, 3 months −20–25, 18 months	—	—
LG Chem	18650HE2	−20–60, 1 month −20–45, 3 months −20–20, 1 year	Charge ≥ 90% after 1 month at 23 °C, 100% SOC	Capacity ≥ 80% after 1 week at 60 °C, 100% SOC
LG Chem	ICR18650MF1	−20–60, 1 month −20–45, 3 months −20–20, 1 year	Charge ≥ 90% after 30 days at 25 °C, 100% SOC	Capacity ≥ 80% after 1 week at 60 °C, 100% SOC
LG Chem	INR18650 B4	−20–60, 1 month −20–45, 3 months −20–20, 1 year	Charge ≥ 90% after 30 days at 25 °C, 100% SOC	Capacity ≥ 80% after 1 week at 60 °C, 100% SOC
A123	AMP20m1HD-A	−40–60	—	—
A123	ANR26650m1-B	−40–60	—	—

Manufacturer	Model	Storage Temperature (°C)	Charge Retention	Capacity Retention
ATL	**902738**	**—**	**The cell voltage for long-time storage shall be 3.6–3.9 V at 25 ± 3 °C after 3 months**	**—**
Routejade	**SLPB8043128H**	**40–60 for up to 1 week 25–40 for up to 3 months −20–25 for up to 1 year**	**Charge ≥ 75% after 1 week at 60 °C, 100% SOC**	**—**
Routejade	**SLPB526495**	**40–60 for up to 1 week 25–40 for up to 3 months −20–25 for up to 1 year**	**Charge ≥ 75% after 1 week at 60 °C, 100% SOC**	**—**
EEMB	**LIR18650**	**1 month: −5–35 °C; 6 months: 0–35 °C.**	**Discharge time ≥4 h after 12 months storage at 40–50% SOC at 25 °C, 65 ± 20% RH**	**—**
EEMB	**LIR1632**	**1 month: −20–60 °C 3 months: −20–45 °C 12 months: −20–25 °C**	**Electricity Charge: 80% after 28 days at 20 °C at 100% SOC**	**Capacity fade over storage time at 20, 40, 60 °C**
GMB	**GMB043450S**	**Less than 1 year: −20–25 Less than 3 months: −20–40**	**—**	**—**
VPW	**580013**	**—**	**—**	**—**
VPW	**580049**	**—**	**—**	**—**
Toshiba	**Toshiba-LTO-20AH**	**—**	**—**	**The capacity fade over float storage time at 25, 35 and 45 °C, 2.7 V**
Johnson Controls-SAFT	**MP 174865 xlr**	**Recommended: 10–30 Allowable: −40–60**	**—**	**—**

— This term is not mentioned.

Nine datasheets specify the amount of charge left in a battery after being stored at 100% SOC. Five datasheets specify the capacity retention after storage. Particularly, EEMB LIR1632 provides the capacity fade over storage time at three different temperatures. ATL 902738 specifies the cell voltage after storage. Toshiba provides the capacity fade over float storage at 2.7 V at three different temperatures.

4. Discrepancies in Datasheets for the Same Battery Model

For Panasonic NCR18650B cells, three different datasheets are found online [16][17][15]. The specified capacity and nominal voltage are the same; however, the physical parameters, charge/discharge characteristic curves, and cycling characteristics curves are all different. **Figure 1** compares the charge curves. The charging C-rate is 0.5 C in “The Charge Characteristics for NCR18650B” Plot [16] and “Charge Characteristics” Plot [15] and 0.3 C in “TYPICAL CHARGE CHARACTERISTICS” plot [17].

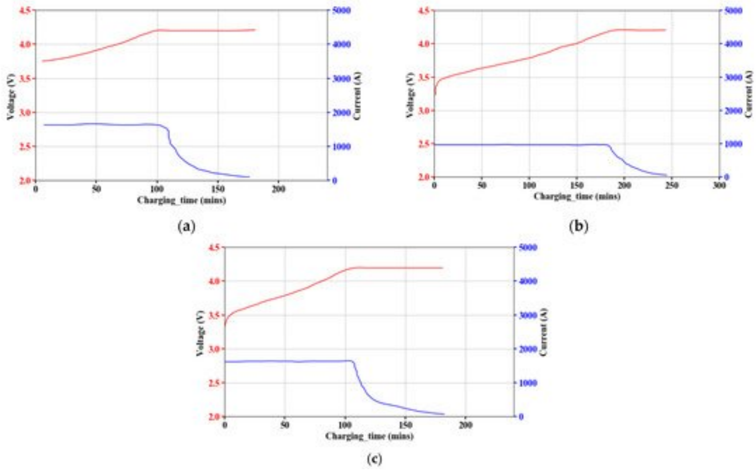

Figure 1. Observed inconsistent charge characteristics from different sources for Panasonic NCR18650B cells: (**a**) [16]; (**b**) [17]; and (**c**) [15].

Figure 2 and **Figure 3** shows that compares that the discharge characteristic curves are inconsistent with each other at the same discharge C-rate and temperature. The discharge curves have significant variation. This may be due to a change in the electrode and electrolyte properties or variation in the manufacturing batch. These should be clarified in the datasheet so customers can select the right product for their targeted application.

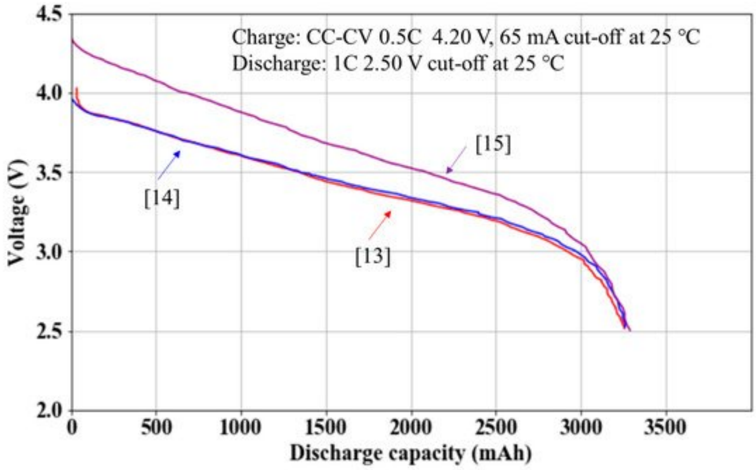

Figure 2. Observed inconsistent discharge characteristics at 25 °C, 1 C from different sources for Panasonic NCR18650B cells.

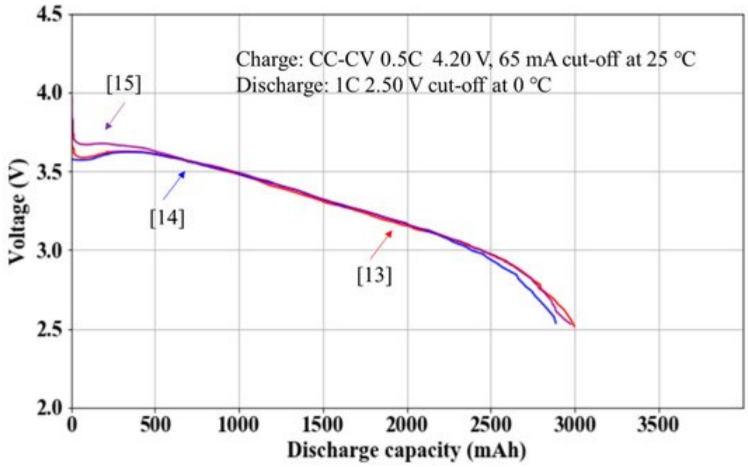

Figure 3. Observed inconsistent discharge characteristics at 0 °C, 1 C from different sources for Panasonic NCR18650B cells.

Figure 4 shows there is a distinct difference between the cycling performance in the two data sheets [17][15]. This all results in confusion for low-volume battery customers who do not have direct communication access with battery manufacturers. Thus, battery manufacturers should provide the official datasheet for clarification for commercial-off-the-shelf battery models sold on various third-party sales websites. The battery manufacturer should confirm the credentials of distributors and third-party sales websites.

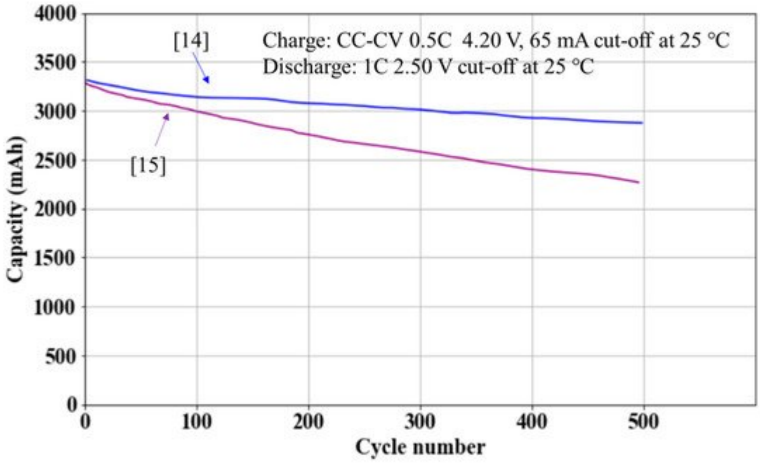

Figure 4. Inconsistency observed in the cycle characteristics from different sources for Panasonic NCR18650B cells.

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