World Academy of Science, Engineering and Technology
International Journal of Energy and Power Engineering
Vol:17, No:10, 2023

Evaluating the Durability and Safety of Lithium-Ion Batteries in High-Temperature Desert Climates

Kenza Maher, Yahya Zakaria, Noora S. Al-Jaidah

***Abstract*—**Temperature is a critical parameter for lithium-ion battery performance, life, and safety. In this study, four commercially available 18650 lithium-ion cells from four different manufacturers are subjected to accelerated cycle aging for up to 500 cycles at two different temperatures (25 °C and 45 °C). The cells are also calendar-aged at the same temperatures in both charged and discharged states for six months to investigate the effect of aging and temperature on capacity fade and state of health. The results showed that all battery cells demonstrated good cyclability and had a good state of health at both temperatures. However, the capacity loss and state of health of these cells are found to be dependent on the cell chemistry and aging conditions, including temperature. Specifically, the capacity loss is found to be higher at the higher aging temperature, indicating the significant impact of temperature on the aging of lithium-ion batteries.

***Keywords*—**Lithium-ion battery, aging mechanisms, cycle aging, calendar aging.

I. Introduction

As the 21st century progresses, global energy consumption and the resulting production of climate-altering stressors, such as waste heat, water vapor, and carbon dioxide, continue to increase at an alarming rate [1], [2]. To address the growing demand for energy while reducing fossil fuel emissions, renewable energy sources like solar, wind, and hydropower are being pursued as viable alternatives. In addition, the widespread adoption of electric vehicles (EVs) in place of gasoline-powered transportation has the potential to significantly reduce greenhouse gas emissions [3].

In recent years, there has been a significant push towards the adoption of renewable energy sources to reduce greenhouse gas emissions and address climate change. One of the key technologies that have emerged in this context is the lithium-ion battery (LIB), which has been widely used in EVs and other energy storage applications due to its high energy density, fast charging capability, and durability [4]-[6]. As the world transitions towards a low-carbon future, understanding the performance and limitations of LIBs becomes increasingly important.

LIBs are still facing some barriers that limit their application space [7], [8]. One of the major limitations of the technology is the impact of temperature. In general, impacts from temperature can be divided into two categories: low temperature effects and high temperature effects [9]-[13]. At low operating temperatures, LIBs show slow chemical-reaction activity and charge-transfer rapidity [14], which leads to the decrease of ionic conductivity in the electrolytes [15] and lithium-ion diffusivity within the electrodes [16]. Such decrease leads to reduction of energy and power capability, and sometimes performance degradation. The effects at high temperatures are much more complex than those at low temperatures.

The high temperature effects lead to the aging of the batteries and degradation of their performance, including the loss of capacity, power, and reducing their lifetime [17]-[19]. In general, the aging of LIBs includes cycle aging and calendar aging [20], [21]. These two types of aging, however, always occur in combination due to the complex composition and working process of LIBs. Controlling and decreasing the aging process is one of the most critical challenges in advanced battery development, which begins by a good understanding of the underlying aging mechanisms.

Cycle aging and calendar aging are two major factors that contribute to the degradation of lithium-ion batteries. Cycle aging occurs during the charge and discharge cycles of the battery, leading to loss of lithium inventory, active material, and increased impedance [22]. On the other hand, calendar aging refers to the degradation processes that occur over time, regardless of the charge/discharge cycles. The impact of calendar aging on battery performance is equally significant, as it can result in capacity loss and reduced overall health of the battery [23].

This study aims to investigate the effects of temperature and storage state on the aging mechanisms of commercial lithium-ion cells in the 18650 formats from different manufacturers. Specifically, the cells are subjected to cycling at two different temperatures (25 °C and 45 °C) for 500 cycles and storage at charge (100%) and discharge (0%) states at the same temperatures for six months. The capacity loss and state of health of the cells are monitored and analyzed to understand the aging mechanisms and provide insights for future battery design and management.

II. Experimental Setup

Cylindrical commercial 18650 lithium-ion cells (Fig. 1) from four different manufacturers are investigated in this study. The 18650 cell is a cylindrical cell with a diameter of 18 mm and a length of 65.0 mm. The specifications and chemistries of the cells, obtained from their technical data sheets, are listed in Table I.

Kenza Maher is with Qatar Environment and Energy Research Institute (QEERI) at Hamad Bin Khalifa University (HBKU), Qatar Foundation (QF), Doha, Qatar (corresponding author, phone: +974-445-48121; e-mail: kmaher@hbku.edu.qa).

Yahya Zakaria and Noora S. Al-Jaidah are with QEERI at HBKU, QF, Doha, Qatar (e-mail: yzakaria@hbku.edu.qa, naljaidah@hbku.edu.qa).

A. Electrochemical Measurements

Electrochemical measurements are performed using the Arbin Instrument battery cycler (model BT-2000) combined with the VTL 4003 Votsch Temperature Test System, with two pairs of wires used for the charge/discharge cycling process at both temperatures (25 °C and 45 °C).

B. Aging Mechanisms

All experimental aging studies presented in this work followed an identical base structure. Firstly, the cells underwent three standard charge and discharge cycles at a C/3 rate. The cells are charged using a constant current/constant voltage (CC-CV) protocol up to 4.2 V, after which the voltage is held at 4.2 V until the current dropped to 0.01C, and then discharged at the same rate down to 2.5 V.

Accelerated cycling aging tests are conducted at a 1C current rate and end after 500 cycles at both 25 °C and 45 °C. In addition to cycling aging tests, calendar tests are also performed for six months at both 25 °C and 45 °C, for both fully charged (100%) and discharged (0%) states. After aging, cells are cycled three times using a standard charge/discharge cycle at a C/3 rate and at room temperature.

To assess the reproducibility of the cycle and calendar aging measurements, the experiments are conducted on two identical cells for each test.

TABLE I
CHARACTERISTIC PROPERTIES OF THE EXAMINED LITHIUM-ION CELLS

Cell	Type A	Type B	Type C	Type D
Manufacture	Panasonic	Sony	LG	Samsung
Type	NCR18650 B	US18650VT C5	INR18650-HE4	INR18650-25R
Nominal Capacity (Ah)	3.35	2.6	2.5	2.5
Average Voltage (V)	3.7	3.7	3.7	3.7
Charging Voltage (V)	4.2	4.2	4.2	4.2
Discharging Voltage (V)	2.5	2.5	2.5	2.5
Anode Material	Graphite	Graphite	Graphite +SiOx	Graphite
Cathode Material	NCA	NCA	NMC	NMC

Fig. 1 Cylindrical commercial 18650 lithium-ion examined cells

III. RESULTS AND DISCUSSION

A. Characteristics of Li-Ion Battery Cells

a. Capacity Determination

The capacity (C) of a battery refers to the total amount of electric charge involved in the electrochemical reaction. Typically, capacity is measured in ampere-hours (Ah) and represents the total number of hours that a fully charged battery can provide a specific current under specified conditions. The capacity can be calculated using (1):

$$C\ (Ah) = I\ (A)\ X\ t\ (h) \tag{1}$$

Here, I is the current measured during the charge/discharge process, and t is the time taken to fully charge or discharge a battery cell.

b. Energy Determination

The energy (E) of a battery cell refers to the total amount of energy it can store and deliver over its lifetime, and it has a significant influence on the battery cell's lifespan. The energy can be expressed in watt-hours (Wh) using (2):

$$E\ (Wh) = Vav\ (V)\ X\ \ C\ (Ah) \tag{2}$$

where, Vav is the average voltage value during discharge, which is obtained by integrating the discharge voltage over time and dividing by the discharge duration. C is the capacity measured during discharge.

c. Power Determination

The power (P) of a battery cell refers to the total amount of power it can deliver, and it is typically calculated using (3):

$$P\ (W) = V(V)\ X\ \ I\ (A) \tag{3}$$

Here, V is the voltage of the battery cell, and I is the current that it can deliver. The power is measured in watts (W).

Table II summarizes the charge and discharge performance of the four different Li-ion battery cells based on (1)-(3), including their charge capacity, discharge capacity, charge energy, discharge energy, charge power, and discharge power.

TABLE II
CHARACTERISTICS OF LI-ION BATTERY CELLS: CAPACITY, ENERGY AND POWER DURING CHARGE AND DISCHARGE PROCESSES

Cells	Charge Capacity [Ah]	Discharge Capacity [Ah]	Charge Energy [Wh]	Discharge Energy [Wh]	Charge Power [W]	Discharge Power [W]
Type A	3.20	3.20	11.84	11.84	3.95	3.95
Type B	2.55	2.55	9.435	9.435	3.14	3.14
Type C	2.50	2.50	9.25	9.25	3.08	3.08
Type D	2.50	2.50	9.25	9.25	3.08	3.08

Cell type A cell showed the highest charge and discharge capacity and energy among all types, while cell types B, C, and D had similar values of these parameters. Moreover, all four cell types had similar charge and discharge power values, indicating that they can provide similar power outputs during charging and discharging processes.

These results suggest that cell type A cell is a high-performance Li-ion battery, with the highest capacity and energy among all types, while cell types B, C, and D can provide similar performance.

The superior performance of cell type A can be attributed to the utilization of high-quality materials in its electrode design, an efficient manufacturing process, and superior design features. Therefore, this cell type is well-suited for high-performance Li-ion battery applications.

B. Accelerated Cycling and Calendar Aging

Aging is typically cycle aging and calendar aging. While cycle aging generally comprises the aging mechanisms that damage the materials reversibility, calendar aging results mainly from interactions between the active materials and the electrolyte [24].

Calendar aging is strongly linked to electrolyte reduction and oxidation and the growth of surface films on the active materials. It strongly depends on time, state of charge (SOC), and temperature [25].

Cycle aging comprises also the mechanisms of structural and mechanical changes in the battery components. It is substantially more complex than calendar aging and depends also on a variety of additional parameters, such as charging and discharging currents, cycle cut-off voltage, and charge throughput [26], [27].

Usually, calendar aging and cycle aging are considered as additive [24]. In practical aging studies where the cells are cycled continuously, it is not possible to measure the individual contributions of cycle and calendar aging, as calendar aging also occurs during the periods of charge/discharge cycling.

To evaluate aging, several indicators or metrics are used, with actual capacity being the most commonly used indicator. It is well known that battery cells suffer from capacity loss during cycling and storage at high temperature. The capacity loss can be classified as reversible (ΔQ_r) and irreversible capacity loss (ΔQ_{ir}) [28]. ΔQ_r is defined as loss that can be fully recovered in the subsequent cycles under low-current conditions. The origin of ΔQ_r is still under debate. Extensive studies have been performed to investigate irreversible capacity loss (ΔQ_{ir}) [29]-[31]. ΔQ_{ir} does not originate from a single aging process but rather combines various processes and their interactions.

Cyclable Li-ion loss and electrode material decay are the most important degradation mechanisms. The irreversible capacity loss is typically expressed by (4):

$$\Delta Qi(\%) = \frac{Nominal\ capacity - remaining\ capacity}{Naminal\ capacity}\ x\ 100 \quad (4)$$

The state of health (SOH) is the most commonly used indicator in the literature to quantify the health level of the battery. It is generally defined by [29], [30]:

$$SOH(\%) = \frac{Remaining\ capacity}{Nominal\ capacity}\ x\ 100 \quad (5)$$

Table III presents the capacity loss of the aged cycle lithium-ion cells. The cells are subjected to 500 cycles at two different temperatures (25 °C and 45 °C) at a 1C rate. After aging, all cells are cycled at a C/3 rate for three standard cycles at 25 °C to compare their capacity loss and SOH with that of fresh cells.

TABLE III
CAPACITY LOSS OF THE CYCLE-AGED LITHIUM-ION CELLS, UP TO 500 CYCLES AT TEMPERATURES OF 25 °C AND 45 °C

Cells	Aging Conditions	Capacity Loss (ΔQir, %)
Type A- Cell#1	500 cycles @ 25°C	8
Type B- Cell#1	500 cycles @ 25°C	6
Type C- Cell#1	500 cycles @ 25°C	10
Type D- Cell#1	500 cycles @ 25°C	13
Type A- Cell#2	500 cycles @ 45°C	12
Type B- Cell#2	500 cycles @ 45°C	10
Type C- Cell#2	500 cycles @ 45°C	14
Type D- Cell#2	500 cycles @ 45°C	16

Based on the results, it can be seen that all four cell types experienced capacity loss after 500 cycles. Cell types B and A demonstrated the lowest and second-lowest capacity loss, respectively, under both aging conditions. Cell types D and C showed the highest and second-highest capacity loss, respectively, under both aging conditions.

By comparing the capacity loss results of the same type of cell under the two aging conditions, it is evident that all four cell types suffered from a higher capacity loss at 45 °C than at 25 °C, which suggests that high temperature can lead to more significant aging effects and capacity degradation in Li-ion batteries.

Table IV presents the capacity loss of the stored lithium-ion cells at both charge and discharge states, which are stored in a temperature chamber for six months at temperatures of 25 °C and 45 °C. After storage, all cells are cycled at a C/3 rate for three standard cycles at 25 °C to compare their capacity loss and SOH with that of fresh cells.

The results show that for cells stored at 100% SOC, cell type B#3 stored at 25 °C had the lowest capacity loss of 1%, while cell type D#4 stored at 45 °C had the highest capacity loss of 7%. For cells stored at 0% SOC, it can be observed that cell type B#5 stored at 25 °C had no capacity loss, while cell type D#5 stored at 25 °C had the highest capacity loss of 3%. Similarly, for cells stored at 0% SOC and 45 °C, cell type B#6 had the lowest capacity loss of 1%, while cell type D#3 had the highest capacity loss of 4%.

Moreover, cells stored at 100% SOC experienced higher capacity loss than cells stored at 0% SOC. This is expected since storing cells at high SOC can lead to increased degradation of the cell's electrode materials.

The cells stored at 45 °C also exhibited higher capacity loss than cells stored at 25 °C. This is due to the accelerated aging of the cells at higher temperatures. Higher temperatures can increase the rate of chemical reactions within the cell, leading to faster degradation of the cell's materials.

Cell types B and A demonstrated relatively better performance under the six aging conditions, while cell types D and C exhibited higher capacity loss.

TABLE IV
CAPACITY LOSS OF THE STORED LITHIUM-ION CELLS AT BOTH CHARGE (100%) AND DISCHARGE (0%) STATES FOR 6 MONTHS AT TEMPERATURES OF 25 °C AND 45 °C

Cells	Aging Conditions	Capacity Loss (ΔQir, %)
Type A- Cell#3	Stored at 100% SOC @ 25°C	2
Type B- Cell#3	Stored at 100% SOC @ 25°C	1
Type C- Cell#3	Stored at 100% SOC @ 25°C	4
Type D- Cell#3	Stored at 100% SOC @ 25°C	5
Type A- Cell#4	Stored at 100% SOC @ 45°C	3
Type B- Cell#4	Stored at 100% SOC @ 45°C	2
Type C- Cell#4	Stored at 100% SOC @ 45°C	5
Type D- Cell#4	Stored at 100% SOC @ 45°C	7
Type A- Cell#5	Stored at 0% SOC @ 25°C	1
Type B- Cell#5	Stored at 0% SOC @ 25°C	0
Type C- Cell#5	Stored at 0% SOC @ 25°C	2
Type D- Cell#5	Stored at 0% SOC @ 25°C	3
Type A- Cell#6	Stored at 0% SOC @ 45°C	2
Type B- Cell#6	Stored at 0% SOC @ 45°C	1
Type C- Cell#6	Stored at 0% SOC @ 45°C	3
Type D- Cell#6	Stored at 0% SOC @ 45°C	4

Overall, these results suggest that the choice of battery cell chemistry and operating conditions can significantly impact the performance and lifespan of Li-ion batteries.

Fig. 2 presents the results of the aging test conducted on four different types of cells, each represented by two cells (Cell#1 and Cell#2) that have undergone 500 cycles at two different temperatures (25 °C and 45 °C). The aging condition is an important factor that affects the health of the cells, and the state of health (SOH %) is a measure of the cells' capacity to store energy compared to their original capacity.

For the cells cycled at 25 °C, cell type B performed the best overall with an average SOH % of 94, followed by cell type A with an average SOH % of 92. Cell type C had the average SOH % of 90, while cell type D had the lowest SOH % of 87.

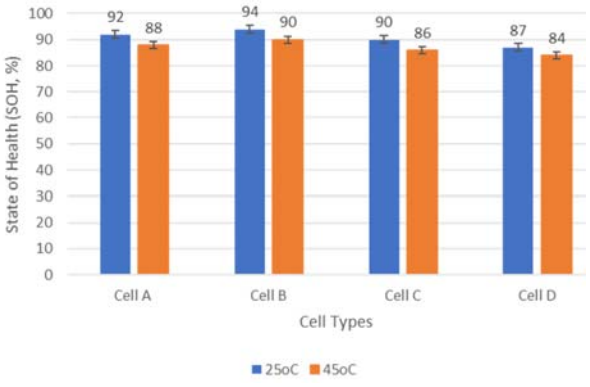

Fig. 2 State of heat of the cycle-aged lithium-ion cells, up to 500 cycles at temperatures of 25 °C and 45 °C

In addition, the cells that are aged at 25 °C generally performed better than those aged at 45 °C. All cells aged at 25 °C had an SOH higher than that of the same cell type aged at 45 °C. This suggests that higher temperatures have a more significant impact on the cells' aging process.

Overall, the results suggest that cell type B may be the most suitable for applications where longevity and stability are critical factors, and that lower temperatures should be used to extend the lifespan of the cells. The variability in performance between cells of the same type also highlights the importance of quality control in the manufacturing process.

Fig. 3 shows the SOH charts of a test conducted on four different types of cells, each represented by two cells (Cell#3 and Cell#5) that are stored for 6 months under two different SOC conditions (100% and 0%) at room temperature (25 °C).

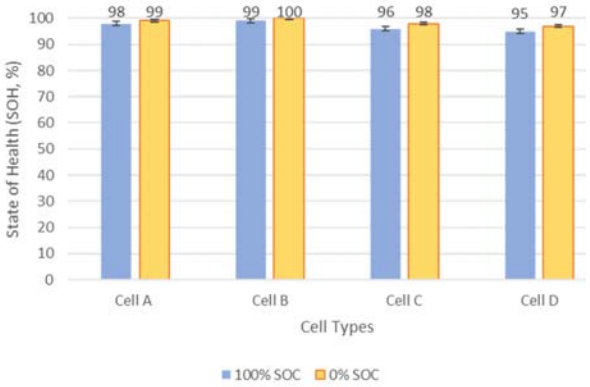

Fig. 3 SOH of the stored lithium-ion cells at both charge (100%) and discharge (0%) states for six months at temperature of 25 °C

Cell type B performed the best overall SOH, followed by cell type A, while cell type D had the lowest SOH. The cells that are stored at 0% SOC generally performed better than those stored at 100% SOC.

Fig. 4 shows the SOH charts of a test conducted on four different types of cells, each represented by two cells (Cell#4 and Cell#6) that are stored for 6 months under two different SOC conditions (100% and 0%) at high temperature (45 °C).

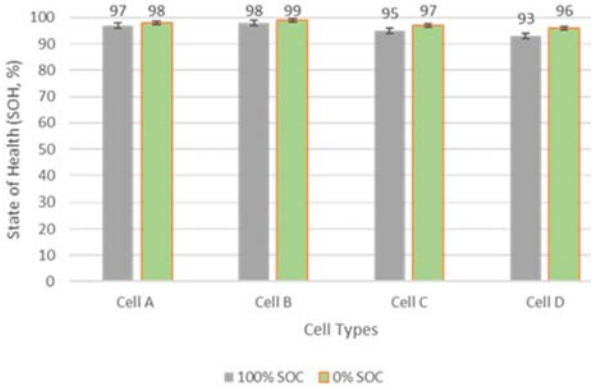

Fig. 4 The stored lithium-ion cells at both charge (100%) and discharge (0%) states for six months at temperature of 45 °C

From the results, we can see that for Cells #4, the SOH % values for cell types B and A are higher compared to cell types C and D. Additionally, for Cells #6, we can see that the SOH % values for cell type B are the highest, followed by cell types A, C, and D. This suggests that the cell type B have better longevity and is more resistant to degradation when stored at high temperature of 45 °C.

In summary, these findings highlight the importance of

temperature and SOC control in mitigating capacity fade and prolonging the life and performance of lithium-ion batteries. Lower temperatures and lower states of charge are generally associated with better state of cell health and lower capacity loss. Furthermore, it is essential to carefully select cell chemistry and operating conditions, including temperature and SOC, to ensure optimal battery performance and safety, especially in hot desert conditions.

IV. Conclusion

LIB, as the primary energy storage solution for the transportation and stationary sectors, is an integral part of current research. Furthermore, aging effects occur at every moment of the battery's life and are one of the most critical factors affecting this technology.

In conclusion, our study focused on investigating the aging mechanisms of four commercial 18650 LIB cells from different manufacturers. We utilized various methods to measure their capacity loss and SOH before and after aging. Our findings indicate that temperature is a critical factor that affects the performance and lifespan of lithium-ion batteries. Specifically, the capacity loss and SOH of all cells showed a strong dependence on the cycling and storage temperature.

Therefore, careful selection of cell chemistry and operating conditions, including temperature control, can help to mitigate the impact of aging and ensure optimal battery performance and safety. By implementing these measures, we can prolong the lifespan and enhance the performance of lithium-ion batteries, which are essential components for both transportation and stationary sectors. This research contributes to the understanding of aging effects and can aid in the development of new and improved battery technologies for future applications.

References

[1] T.M. Gür, "Review of electrical energy storage technologies, materials and systems: challenges and prospects for large-scale grid storage," Energy Environ. Sci., vol. 11, pp. 2696-2767, 2018

[2] M.A. Hannan, M.S.H. Lipu, P.J. Ker, R.A. Begum, V.G. Agelidis, F. Blaabjerg, "Power electronics contribution to renewable energy conversion addressing emission reduction: applications, issues, and recommendations," Appl. Energy, vol. 251, pp. 113404, 2019

[3] S. Pacala, R. Socolow, "Stabilization wedges: solving the climate problem for the next 50 years with current technologies," Science, vol. 305, pp. 968-972, August 2004

[4] H. Zhang, H. Zhao, M.A. Khan, W. Zou, J. Xu, L. Zhang, J. Zhang, "Recent progress in advanced electrode materials, separators and electrolytes for lithium batteries," J. Mater. Chem., vol. 6, pp. 20564-20620, 2018

[5] G.L. Zhu, C.Z. Zhao, J.Q. Huang, C. He, J. Zhang, S. Chen, L. Xu, H. Yuan, Q. Zhang, "Fast charging lithium batteries: Recent progress and future prospects," Small, vol. 15, pp. 1-14, 2019

[6] X. Lin, M. Salari, L.M.R. Arava, P.M. Ajayan, M.W. Grinstaff, "High temperature electrical energy storage: Advances, challenges, and frontiers," Chem. Soc. Rev., vol. 45, pp. 5848-5887, 2016

[7] J.M. Tarascon, M. Armand, Issues and challenges facing rechargeable lithium batteries, Nature, vol. 414, pp. 359-367, 2001

[8] J.B. Goodenough, Y. Kim, "Challenges for rechargeable Li batteries," Chem. Mater., vol. 22, pp. 587-603, 2010

[9] C.K. Huang, J.S. Sakamoto, J. Wolfenstine, S. Surampudi, "The limits of low-temperature performance of Li-ion cells," J. Electrochem. Soc., vol. 147, pp. 2893-2896, 2000

[10] G. Nagasubramanian, "Electrical characteristics of 18650 Li-ion cells at low temperatures," J. Appl. Electrochem., vol. 31, pp. 99-104, 2001

[11] M. Brousselya, S. Herreyre, P. Biensan, P. Kasztejna,K. Nechev, R.J. Staniewicz, "Aging mechanism in Li ion cells and calendar life predictions," J. Power Sources, vol. 97-98, pp. 13-21, 2001

[12] K. Amine, C.H. Chen, J. Liu, M. Hammond, A. Jansen, D. Dees, I. Bloom, D. Vissers, G. Henriksen, "Factors responsible for impedance rise in high power lithium-ion batteries," J. Power Sources, vol. 97-98, pp. 684-687, 2001

[13] T. Waldmann, M. Wilka, M. Kasper, M. Fleischhammer, M. Wohfahrt-Mehrens, "Temperature dependent ageing mechanisms in Lithium-ion batteries - A Post-Mortem study," J. Power Sources, vol. 262, pp. 129-135, 2014

[14] Y. Ji, Y. Zhang, C.Y. Wang, "Li-ion cell operation at low temperatures," J. Electrochem. Soc., vol. 160, pp. A636-A649, 2013

[15] H.C. Shiao, D. Chua, H.P. Lin, S. Slane, M. Salomon, "Low temperature electrolytes for Li-ion PVDF cells," J. Power Sources, vol. 87, pp. 167-173, 2000

[16] S.S. Zhang, K. Xu, T.R. Jow, "Low temperature performance of graphite electrode in Li-ion cells," Electrochim. Acta, vol. 48, pp. 241-246, 2002

[17] P. Ramadass, B. Haran, R. White, B.N. Popov, "Capacity fade of Sony 18650 cells cycled at elevated temperatures: Part II. Capacity fade analysis," J. Power Sources, vol. 112, pp. 614-620, 2002

[18] J.R. Belt, C.D. Ho, T.J. Miller, M.A. Habib, T.Q. Duong, "The effect of temperature on capacity and power in cycled lithium-ion batteries," J. Power Sources, vol. 142, pp. 354-360, 2005

[19] Y. Zhang, C.Y. Wang, X. Tang, "Cycling degradation of an automotive $LiFePO_4$ lithium-ion battery," J. Power Sources, vol. 196, pp. 1513-1520, 2011

[20] T.G. Zavalis, M. Klett, M.H. Kjell, M. Behm, R.W. Lindström, G. Lindbergh, "Aging in lithium-ion batteries: Model and experimental investigation of harvested $LiFePO_4$ and mesocarbon microbead graphite electrodes," Electrochim. Acta, vol. 110, pp. 335-348, 2013

[21] M. Ecker, N. Nieto, S. Käbitz, J. Schmalstieg, H. Blanke, A. Warnecke, D.U. Sauer, Calendar and cycle life study of $Li(NiMnCo)O_2$-based 18650 lithium-ion batteries, J.Power Sources, vol. 248, pp. 839-851, 2014

[22] A. Barré, B. Deguilhem, S. Grolleau, M. Gérard, F. Suard, D. Riu, "A review on lithium-ion battery ageing mechanisms and estimations for automotive applications," J. Power Sources, vol. 241, pp. 680-689, 2013

[23] M. Safari, C. Delacourt, "Aging of a Commercial Graphite/$LiFePO_4$ Cell," J. Electrochem. Soc., vol. 158, pp. A1123-A1135, 2011

[24] W.A. van Schalkwijk, B. Scrosati, "Advances in lithium-ion batteries," Kluwer Academic/Plenum Publishers, New York, NY, 2002

[25] E. Sarasketa-Zabala, I. Gandiaga, L.M. Rodriguez-Martinez, I. Villarreal, "Calendar ageing analysis of a $LiFePO_4$/graphite cell with dynamic model validations," J. Power Sources, vol. 272, pp. 45-57, 2014

[26] J. Wang, J. Purewal, P. Liu, J. Hicks-Garner, S. Soukazian, E. Sherman, A. Sorenson, L. Vu, H. Tataria, M.W. Verbrugge, "Degradation of lithium-ion batteries employing graphite negatives and nickel-cobalt-manganese oxide + spinel manganese oxide positives: Part 1, aging mechanisms and life estimation," J. Power Sources, vol. 269, pp. 937-948, 2014

[27] J. Schmalstieg, S. Käbitz, M. Ecker, D.U. Sauer, "A holistic aging model for $Li(NiMnCo)O_2$ based 18650 lithium-ion batteries," J. of Power Sources, vol. 257, pp. 325-334, 2014

[28] D. Guyomard and J. M. Tarascon, "The carbon/$Li_{1+x}Mn_2O_4$ system," Solid State Ionics, vol. 69, pp. 222-237, 1994

[29] A. Widodo, M.C. Shim, W. Caesarendra, B.S. Yang, "Intelligent prognostics for battery health monitoring based on sample entropy," Expert Systems with Applications, vol. 38, pp. 11763-11769, 2011

[30] Y. Xing, K.L. Tsui, N. Williard, M. Pecht, "A comparative review of prognostics-based reliability methods for lithium batteries", *Prognostics and System Health Management Conference (PHM-Shenzhen)*, pp. 1-6, 2011.