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Insights on the degradation mechanism of 7 Ah sodium ion batteries at different aging modes



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HIGHLIGHTS

- The chemical and electrochemical degradation mechanisms of SIBs were revealed.
- Multi-level analysis methods are used to uncover the failure mechanism of SIBs.
- The contribution capacity loss of SIBs has been successfully decomposed.

GRAPHICAL ABSTRACT



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ABSTRACT

Sodium ion batteries (SIBs) are considered to have significant advantages in the field of energy storage due to their abundant resources. However, SIBs are exposed to complex and adverse environments, making it particularly important to study the capacity degradation mechanism under extreme conditions. In this study, the 7.3 Ah SIBs with Na₄Fe₃(PO₄)₂P₂O₇ (NFPP) and hard carbon (HC) as cathode and anode are taken as the research objects. The capacity degradation experiment of SIBs is conducted under different aging modes. Subsequently, comprehensive non-destructive and post-mortem analyses are combined to explore the failure mechanism of SIBs. This study indicates that the loss of active sodium and the increase of interface impedance are the main reasons for the capacity decay of SIBs. In particular, during the room temperature cycling, sodium plating is the

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main source of capacity loss. Additionally, during the high-temperature aging process, polarization caused by interface side reactions is the main reason. Surprisingly, throughout the entire aging test, the structures of NFPP and HC do not show significant deterioration, indicating that SIBs also have great potential for application in high-temperature scenarios. This study reveals the failure mechanism of SIBs, which provides reference for battery design and material research.

1. Introduction

Over the past decades, the requirement for low-cost, long-life, and high-safety energy storage technologies has been continuously increasing in order to achieve efficient utilization of clean energy [1–3]. During this period, lithium-ion batteries (LIBs) have experienced rapid development and have been successfully applied in various fields such as electronic products, portable energy storage, and electric vehicles [4,5]. Unfortunately, due to the scarcity and uneven distribution of lithium resources, the large-scale application of LIBs is limited [6]. Sodium ion batteries (SIBs) are considered an important supplement to LIBs, due to their abundant resources and advantages in low-temperature cycling and rate performance. However, in reality, this performance is closely related to the cathode and anode materials and battery design [7–9].

In long-term research, both cathode and anode materials of SIBs have shown excellent electrochemical performance. For cathodes, layered oxide cathode with high theoretical specific capacity and polyanion cathode materials with stable structure have become the focus of research [7,10]. Among these materials, iron-based mixed polyanionic material stands out due to its low cost, high safety, and long cycle life [11]. The iron-based mixed polyanion material Na₄Fe₃(PO₄)₂P₂O₇ (NFPP) prepared by Mai et al. exhibits a high capacity retention rate of 80.8 % at 5 A g⁻¹ after 14000 cycles [12]. In addition, Wang et al. used a high entropy strategy to modify NFPP, which showed an impressively high capacity of 122.3 mAh g^{-1} at 0.1 C and maintained performance for 14000 cycles at 50 C [13]. For anode materials, most hard carbon (HC) materials have shown stable high capacity of >300 mAh g⁻¹, which have an absolute advantage among various anode materials of SIBs and can meet the application requirements of commercial anode of SIBs [14-16].

Therefore, the SIBs using NFPP and HC as cathode and anode are considered as one of the most promising SIBs. In addition, these SIBs have also been proven to have excellent cycling stability and lowtemperature discharge capability. Mai et al. assembled full SIBs based on modified NFPP, and the full SIBs showed discharge capacity of approximately 50 mAh g⁻¹ after 200 cycles at 500 mA g⁻¹ [12]. What's more, the Ah-level pouch battery with NFPP and HC assembled by Zhao et al. maintained a capacity retention rate of around 87.4 % after 1000 cycles, demonstrating excellent cycle stability [17,18]. The development of SIBs is shifting from materials to batteries, and from research to products [19]. A comprehensive and systematic evaluation of SIBs failure at the battery level can provide more targeted guidance for material optimization, as well as the design and development of the batteries, especially in failure analysis under important application conditions, which is more conducive to leveraging the characteristics of SIBs [20-22]. Additionally, the capacity degradation of batteries is often accompanied by safety issues, which makes the battery failure analysis more important for the large-scale application of SIBs [23-25].

Herein, the 7.3 Ah cylindrical SIBs (diameter = 33 mm, height = 140 mm) with NFPP and HC as cathode and anode have been preliminarily proven to have high safety and electrochemical performance. And the capacity degradation mechanism of SIBs under different aging modes has been comprehensively studied through a combination of non-destructive analysis and post-mortem analysis. After analysis, it was found that the capacity loss mainly comes from the loss of active sodium and the increase of interface impedance, while both cathode and anode materials maintain excellent structural stability. During the high-temperature cycle/calendar aging process, the conductivity of

electrolyte is increased, and the solid-phase diffusion of sodium ions is accelerated, avoiding sodium plating. However, interface side reactions lead to continuous thickening of solid electrolyte interface (SEI) and solid electrolyte interface (CEI), which increases battery polarization and ultimately results in capacity loss. During the room-temperature cycling process, sodium plating is the main source of capacity loss, and active sodium will further react with the electrolyte, causing safety hazard to the battery. And throughout the entire aging test, the structures of NFPP and HC have not undergone significant deterioration, demonstrating the promising application prospects of SIBs with NFPP and HC as cathode and anode. At the same time, we have demonstrated that NFPP||HC cell is suitable for high-temperature scenarios due to the structural stability of the material at high temperatures. This study reveals the degradation mechanism of SIBs under different temperatures and aging modes, which is expected to provide reference for battery design and management.

2. Experimental

2.1. Battery safety test

The NFPP materials from Anhui Huana New Materials Technology Co., Ltd, are selected as cathodes of SIBs. The HC materials are commercial materials. The electrode design parameters of SIBs are shown in Table S1. These SIBs are filled with ester electrolyte, consisting of 1 M NaPF6 in ethylene carbonate (EC), propylene carbonate (PC) and diethyl carbonate (DEC), and the mass ratio of the three solvent components is 1:1:1, and the injection coefficient is 6 g Ah^{-1} . All safety tests follow international standards. During the heat abuse test, the SIBs (full charge) were heated at a heating rate of 5 °C min⁻¹ \pm 2 °C min⁻¹, until 130 °C \pm 10 °C, and remained constant for 30 min. During the battery overcharging test, the battery was charged at a rate of 1.0 C-1.5 times the charging cutoff voltage. In the forced discharge test, the battery was discharged at a rate of 1.0 C for 90 min. ARC (HEL BTC 130) was used to evaluate the safety performance of the SIBs. The initial temperature of the test was 50 °C, under the adiabatic condition, each step was heated by 5 °C, and the self-generated heat rate detection threshold was 0.02 °C min⁻¹. All the above tests were conducted in an explosion-proof box, and thermocouples, voltmeters, cameras were used to monitor battery temperature, voltage, and status.

2.2. Material characterization

The disassembly of the cylindrical battery was completed in a glove box filled with argon gas, and the electrodes were cleaned multiple times with Dimethyl carbonate (DMC) before analysis (all batteries are fully discharged). The crystallographic structure of the electrodes was determined by using X-ray diffraction (XRD) analysis (Rigaku Miniflex 600 instrument), with a scan rate of 5° min⁻¹ and employing Cu Kα radiation. The surface morphologies of the cathode, anode and separator were characterized by scanning electron microscopy (SEM, Hitachi/ Zeiss). Raman spectroscopy data of HC were obtained by Raman spectrometer (Horiba Xplora). Solid-state nuclear magnetic resonance (ssNMR) was carried out on Bruker AVANCE NEO 600 MHz.

2.3. Electrochemical measurements

The cylindrical batteries used constant current and constant voltage



Fig. 1. Electrochemical and safety performance of SIBs. (a) Optical image of SIBs. (b) Discharge capacity at different discharge rates (the charging rate is 0.5 C). (c) The capacity of SIBs at different temperatures (low temperature). The voltage and temperature evolutions in the process of (d) over-heating test, (e) overcharge test, (f) over-discharge test (inset is the image of SIBs after safety tests). (g, h) The heat-wait-search curves of fully charged 7.3 Ah SIBs (inset is the image of SIBs after thermal runaway).

(CCCV) charging and discharging steps between 1.5 and 3.5 V. And the coin cells used CCCV charging and discharging steps between 1.5 and 3.5 V (NFPP||Na) or 0.01–2.0 V (HC||Na). And all coin cells were assembled using the 2016-type coin cell. In addition, glass fibers (GF/D, Whatman), a counter electrode (Na metal sheet), and electrolyte (Hunan Fenlanite New Energy Technology Co., Ltd.) were also used for coin cell assembly. All the assembly processes were operated in a glove box filled with argon (H₂O, O₂ < 0.5 ppm). Electrochemical impedance spectroscopy (EIS) measurements were performed with electrochemical workstation and the frequency ranged from 10⁵ Hz to 0.1 Hz.

3. Results and discussion

3.1. Battery test and non-destructive analysis

The capacity of the NFPP||HC cylindrical battery (33140, diameter = 33 mm, height = 140 mm) is 7.3 Ah, and the mass and volume energy density are 89.69 Wh/kg and 181.33 Wh/L, respectively. The batteries have excellent consistency and moderate energy density (Fig. 1(a), Figure S1, Table S2). The SIBs exhibit great potential in rate discharge, with no significant capacity and voltage reduction observed as the rate increases from 1.0 C to 4.0 C (Fig. 1(b), Figure S2). Meanwhile, SIBs also demonstrate excellent rate performance, the charge-discharge capacity at 4 C can reach 6.10 Ah (Fig. S3). Moreover, the SIBs exhibit excellent low-temperature discharge performance, with capacity retention rates of 95.02 %, 89.35 %, 81.89 %, and 64.18 % at temperatures of 0 °C, -20 °C, -30 °C, and -40 °C (Compared with the capacity at 25 °C). After low-temperature discharge and then room temperature discharge

again, the capacity can be restored to 99.72 % of the initial capacity (Fig. 1(c), Figure S4, Table S3). Subsequently, the full-charged fresh SIBs underwent safety testing that met international standards. In the tests of overheating, overcharging and over-discharging, the SIBs did not ignite or explode (Fig. 1(d-f)), which exhibited excellent safety. During the SIBs overcharge test, the highest temperature of the battery only reached 79.9 °C, and the battery did not experience thermal runaway even after internal-short circuit. In the overheat and over-discharging tests, there was no significant temperature rise observed in the SIBs. Especially, this SIBs can still be charged and discharged normally after overheat and over-discharge tests (Figure S5 (a, b)). In more stringently adiabatic environment safety test, SIBs experienced thermal runaway (Fig. 1(g and h)), with self-generated heat temperature (T_1) , thermal runaway trigger temperature (T₂, define as dT dt⁻¹ = 1 °C min⁻¹), and maximum thermal runaway temperature (T₃) of 152.0 °C, 190.0 °C, and 285.7 °C, respectively. Compared to LIBs, the safety has been significantly improved [26-28]. And before the thermal runaway occurs, the safety value opens in advance, releasing some combustible gases and electrolytes, which effectively reduces the severity of the thermal runaway. In summary, all of these indicate that the cylindrical SIBs with NFPP and HC as cathode and anode exhibit excellent electrochemical performance and safety, which is basically in line with practical applications. Thereafter, this battery will be used for research on capacity degradation mechanisms.

During the energy storage process, SIBs will experience complex and extremely harsh external environments. In addition, high-safety SIBs are expected to be applied in high-temperature scenarios, therefore, it is particularly important to study the capacity degradation mechanism



Fig. 2. Electrochemical performance during SIBs aging process. (a, b) Voltage-time curves of calendar aging at different temperatures. (c) Capacity loss of SIBs calendar aging at different temperatures. (d–f) Cycle performance of SIBs at different temperatures. (g) The incremental capacity analysis of SIBs under calendar aging at 25 °C and 80 °C. (h, i) The incremental capacity analysis of SIBs under cyclic aging at 25 °C and 80 °C. (h, ii) The incremental capacity analysis of SIBs under cyclic aging at 25 °C and 80 °C.

under extreme conditions. In this study, SIBs were used to investigate the capacity degradation mechanism in high temperature and room temperature scenarios. Herein, SIBs were used for full-charge calendar aging and cycle at 25 °C and 80 °C, respectively, and non-destructive and post-mortem characterization was combined to investigate. During the full-charge calendar aging process, the SIBs at 80 °C showed more significant voltage drop and capacity decay, with a coulombic efficiency (CE) of only 88.90 %, while the CE of aged SIBs at 25 $^\circ C$ was 93.40 % (Fig. 2(a and b)). And the capacity losses were 0.48 Ah and 0.82 Ah, respectively (Fig. 2(c)). This indicates that capacity decay also occurs during the aging process of the fully charged calendar, especially in high-temperature environments. During the cycle process, the capacity retention rate of SIBs is 96.43 % and 92.43 % after 400 cycles at temperatures of 25 °C and 80 °C, respectively (Figure S6, Fig. 2(d-f)). The reasons for the capacity degradation that occurred during these processes are further investigated.

Non-destructive characterization methods are crucial for providing fundamental insights into degradation mechanisms without destroying battery structures. Increment capacity analysis (ICA), as a non-destructive analysis method, is widely used in the analysis of battery aging mechanisms [29,30]. Its most important advantage is to transform the redox reaction of the battery into an easily recognizable capacity increment peak [31]. For NFPP cathode, Na⁺ occupies four different crystal positions in the crystal structure, with different coordination numbers, namely Na3 (five coordination), Na1 (six coordination), Na4 (six coordination), and Na2 (seven coordination) sites [32]. Three

sodium sites can be reversibly extracted or inserted into the crystal, while Na2 is electrochemically inert. The sodium extraction sequence is as follows: first, Na3 and Na1 are extracted, and then Na4 is extracted. The insertion order is reversed [33]. The multiple oxidation/reduction peaks (observed in Fig. S7) indicate the insertion/extraction of sodium ions into different sites within the structure. During the calendar aging process, the oxidation-reduction peak below 3.0 V gradually weakens with the increase of temperature, corresponding to the insertion and extraction reaction sites of Na3 (five coordinated) (Fig. 2 (g)). During the 25 °C cycle process, this oxidation-reduction peak also weakens with the increase of the number of cycles (Fig. 2(h)). More evident, the peak disappears directly after cycling at 80 °C (Fig. 2(i)). In addition, the polarization of the battery significantly increases during the high-temperature cycle process. This phenomenon may be due to the degradation of the cathode structure, which leads to the decrease in the activity of the Na3 site, or the loss of active sodium causing sodium ions to be unable to fully occupy the sites. For this speculation, further verification will be conducted through post-mortem analysis.

3.2. Post-mortem analysis

Through an analysis of capacity, voltage and IC curves of the SIBs above, a preliminary understanding of the capacity degradation mechanism of the battery has been obtained. The failure mechanism will be further revealed through post-mortem analysis. All batteries were fully discharged and disassembled in the glove box filled with argon gas. The



Fig. 3. The image of separator, cathode and anode disassembled from the SIBs with different aging modes (All batteries were disassembled at discharged state).



Fig. 4. SEM images of cathodes under different aging modes: (a) Pristine; (b) Cycle at 25 °C; (c) Calendar aging at 25 °C; (d) Cycle at 80 °C; (e) Calendar aging at 80 °C. SEM images of anodes under different aging modes: (f) Pristine; (g) Cycle at 25 °C; (h) Calendar aging at 25 °C; (i) Cycle at 80 °C; (j) Calendar aging at 80 °C. SEM images of separator under different aging modes: (k) Pristine; (l) Cycle at 25 °C; (m) Calendar aging at 25 °C; (n) Cycle at 80 °C; (o) Calendar aging at 80 °C.

optical images of the separator, cathode, and anode after battery disassembly are shown in Fig. 3. Except for SIBs that have undergone room temperature cycle, there are little differences in the appearance of the cathode, anode and separator between the pristine and degraded battery. Obviously, the anode of SIBs undergoing room-temperature

cycle has severe sodium plating, and the by-products of the reaction between sodium metal and electrolyte adhere to the separator and cathode. This also indicates that the N/P ratio (capacity ratio of anode to cathode) design of battery is not reasonable enough, the conductivity of electrolyte and the solid-phase diffusion of sodium ions are relatively



Fig. 5. Capacity degradation mechanism analysis of cathode materials. (a) Capacity loss of various parts of cathode materials. (b, c) Charging and discharge curve of NFPP||Na coin cells (The NFPP electrodes were obtained from disassembled batteries). (d) Specific capacity loss and capacity loss rate of SIBs. (e) The incremental capacity analysis of cion cell during discharge process. (f) XRD patterns of cathode materials undercoin different aging modes. (g) EIS curve of NFPP||Na coin cells. (h) Schematic diagram of cathode failure.

low. Therefore, the design of electrodes is crucial for the construction of safe SIBs [34,35]. Further, SEM images of pristine and degraded cathode were used to analyze the degradation of NFPP particles and surfaces (Fig. 4(a-e)). The cathodes after calendar aging at 25 °C and 80 °C exhibited the same morphology as that of the fresh cathode with the particles remaining intact. However, particle microcrack is observed in the cathodes cycle at 25 °C and 80 °C, which means that there is a manifestation of slight degradation of the active material during the cycle process (Fig. S8). Particle microcrack can lead to poor intergranular connections and create new sites for surface corrosion and side reactions, thereby accelerating battery capacity degradation [36]. They did not occur during the calendar aging process, indicating that the particle microcracks were structural degradation caused by electrochemical reactions, rather than erosion of the electrolyte at high temperatures. The sodium plating and structural degradation behavior of HC under multiple conditions were observed by SEM (Fig. 4(f-j)). After room-temperature cycle, there is a large-area moss-like sodium plating on HC anode and by-products on separator, while those under other aging modes do not exhibit sodium plating or other obvious phenomena. We analyzed the deposits on the surface of the HC by SEM-EDS (Fig. S9). EDS testing showed that the regions on the HC surface where deposits exist are rich in Na and O elements, with relatively less C. It can be initially speculated that the substance is Na2O (It is caused by the reaction of sodium plating with oxygen in the air during the SEM sample injection process). Combined with further ssNMR testing, it was proven that the deposits on the HC surface are metallic sodium (Fig. S10). In summary, we have confirmed that the deposits on the surface of HC are

sodium plating. SEM is used to further characterize the microstructure of by-products. It can be observed that the ceramic particles of the ceramic separator have been detached, and at the same time, some ceramic particles adhere to the cathode electrode. The position of by-products is very consistent with that of sodium plating, indicating that the by-products are generated by the reaction between active sodium and electrolyte (Figs. S11(a and b)). The stripping of ceramic particles undoubtedly reduces the dimensional stability of the separator and deteriorates the safety of the battery. No significant changes were observed in most areas of the separator under any aging mode (Fig. 4(k-0)).

In order to decompose the contribution of the cathode and anode electrodes to the capacity degradation of the battery in terms of structural degradation, polarization, and other aspects, the disassembled cathode and anode were separately reassembled with sodium metal to form a coin type half-cell. The NFPP||Na half-cells were charged to 3.5 V with a current of 1.1 mA, to calibrate the residual capacity of the cathode materials (Fig. 5(a)). Then, through discharging to 1.5 V, sodium ions insert back into the cathode material to eliminate capacity degradation caused by loss of active sodium (Fig. 5(b)). After testing, it can be preliminarily found that during the process of sodium ions extraction, the cathode materials after high-temperature and roomtemperature cycle only exhibit a capacity of 0.91 mAh and 1.04 mAh (the capacity of pristine cathode is 1.15 mAh), while the capacity of the cathode materials after high-temperature and room-temperature calendar aging is 1.09 mAh and 1.07 mAh, respectively. This explain that the loss of active sodium caused by interface side reactions in hightemperature cycling is more severe than the sodium plating during



Fig. 6. Capacity degradation mechanism analysis of anode materials. (a) Discharge curve of HC||Na coin cells (The HC electrodes were obtained from disassembled batteries). (b) Capacity statistics of different coin cells. (c) XRD patterns of anode materials under different aging modes. (d) Raman spectrum of anode materials under different aging modes. (e) EIS curve of HC||Na coin cells (inset is the equivalent circuit to fit impedance spectra of the batteries.). (f) Schematic diagram of anode failure.

room temperature cycling. When sodium ions embed back into cathode, the active sites of NFPP can be almost completely inserted by sodium ions, and there is no significant difference between the aged cathode material and the pristine sample (Fig. 5(c)). The specific capacity loss of active sodium after cycle (25 °C and 80 °C) is slightly higher than calendar aging (Fig. 5(c and d)). It is worth noting that the loss of active sodium in the pristine SIBs after formation and capacity calibration also reached 13.3 %, indicating that the insufficient initial coulombic efficiency (ICE) of the HC resulted in excessive consumption of active sodium in the battery, thus seriously reducing the capacity utilization of SIBs.

At the same time, we conducted ICA on the discharge curve of the NFPP||Na cells, and found that the reduction peak did not show significant changes compared to the fresh cathode (Fig. 5(e)). Especially, the peak below 3.0 V reappeared in the high-temperature aged cathode material, indicating that the Na3 sites still have electrochemical activity. In the SIBs, the loss of active sodium is the main reason for the disappearance of the Na3 sites peak below 3.0 V, and the structure of NFPP does not significantly deteriorate during the aging process. Significantly, the polarization of the aged cathode materials increases during the charging and discharging process (especially after high-temperature aging). The XRD patterns of cathode materials under different aging modes also indicate that the structure of the cathode materials has not deteriorated and there is no generation of impurities, which also proves the above analysis conclusion (Fig. 5(f)). In addition, the EIS of NFPP Na coin cells was used to further characterize interfacial charge transfer resistance (R_{ct}), all the degraded batteries exhibit increased impedance (Fig. 5(g), Figure S12). At the same time, the R_{ct} of the batteries after high temperature aging also significantly increases (compared to room temperature aging). Impedance data and polarization data have also confirmed each other.

The HC anode is also used to reassemble coin cells for further measurement of sodium storage capacity (HC has selected areas without sodium plating). From the discharge program of constant current and constant voltage (CCCV), the discharge curves of HC before and after aging highly overlap, and there is no significant difference in the sodium storage capacity, plateau capacity, and slope capacity of aged HC compared to fresh HC (Fig. 6(a and b), Fig. S13). This means that the structure of HC (including pseudo-graphite and micropores) has not deteriorate under various aging modes [37,38]. The XRD pattern indicates that the structure parameters such as average interlayer spacing, average layer stacking distance of HC have not undergone significant changes (Fig. 6(c)). Raman spectroscopy (Fig. 1(f)) is further conducted to assess the microstructure of HC. The peak positions of the D and G peaks of HC before and after aging are around 1353 cm⁻¹ and 1594 cm^{-1} , with no significant shift observed, and the I_D/I_G ratio remains unchanged. This indicates that the edge defects and microcrystals of HC are not damaged. Overall, the structure of HC did not show significant deterioration during the aging process. From the interfacial impedance test results of HC anode, it can be found that the SEI impedance (R_{SEI}) and R_{ct} of the aged electrodes both increase significantly, and the impedance increase of the high-temperature aged electrode is more pronounced, which may be due to the side reactions at the HC interface (Fig. 6(e), Figure S14). Therefore, the structure of HC will not be destroyed during the cycling process, and the increase in interfacial impedance is the significant reason for the degradation of battery capacity, especially for batteries aging at high-temperature. During the cycling process at room temperature, the battery exhibits sodium plating, resulting in loss of active sodium and safety hazards (Fig. 6(f)).

4. Conclusion

In this work, NFPP||HC cylindrical battery has been proven to have excellent safety and electrochemical performance. And based on this battery, the capacity degradation mechanism of SIBs under different aging modes has been comprehensively studied through a combination of non-destructive analysis and post-mortem analysis. Overall, the loss of active sodium and the increase of interface impedance are the main causes of capacity degradation. However, the mechanisms of active sodium loss and interface impedance increase are not the same. For batteries undergoing high-temperature aging, severe side reactions at the interfaces of cathode-electrolyte and anode-electrolyte not only result in loss of active sodium, but also sharply increase interface impedance, leading to degradation of battery capacity. In addition, the main reason for capacity degradation at room-temperature cycling batteries is the sodium plating on the surface of anode, which further leads to the SEI regeneration and increased interfacial impedance. Fortunately, the structures of NFPP and HC remain stable under different aging modes, demonstrating the promising application prospects of SIBs with NFPP and HC as cathode and anode, and these SIBs system is also suitable for high-temperature applications. This work comprehensively analyzes the failure mechanism of SIBs and reveals the sources of capacity loss in SIBs under different aging modes, which will provide reference for the design of SIBs.

CRediT authorship contribution statement

Wei Li: Writing – original draft, Investigation, Data curation, Conceptualization. Honghao Xie: Investigation, Data curation. Shini Lin: Investigation. Yuan Qin: Investigation. Jing Zeng: Writing – review & editing, Funding acquisition. Peng Zhang: Writing – review & editing, Funding acquisition. Jinbao Zhao: Writing – review & editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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Appendix A. Supplementary data:

Supplementary data to this article can be found at Supporting Information.

Data availability

Data will be made available on request.

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