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Safety and Quality Issues of Counterfeit Lithium-Ion Cells

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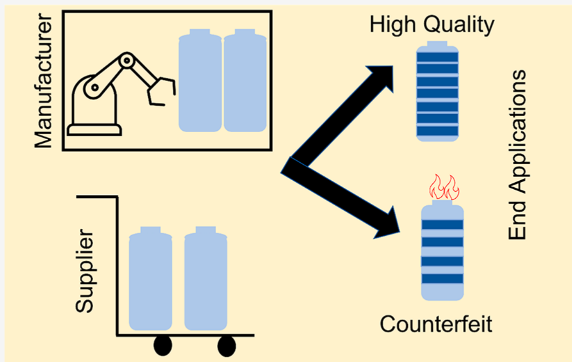
ABSTRACT: Lithium-ion batteries continue to transform consumer electronics, mobility, and energy storage sectors, and the applications and demands for batteries keep growing. Supply limitations and costs may lead to counterfeit cells in the supply chain that could affect quality, safety, and reliability of batteries. Our research included studies of counterfeit and low-quality lithium-ion cells, and our observations on the differences between these and original ones, as well as the significant safety implications, are discussed. The counterfeit cells did not include internal protective devices such as the positive temperature coefficient or current interrupt devices that typically offer protection against external short circuits and over-charge conditions, respectively, in cells from original manufacturers. Poor-quality materials and lack of engineering knowledge were also evident on analyses of the electrodes and separators from low-quality manufacturers. When the low-quality cells were subjected to off-nominal conditions, they experienced high temperature, electrolyte leakage, thermal runaway, and fire. In contrast, the authentic lithium-ion cells performed as expected. Recommendations are provided to identify and avoid counterfeit and low-quality lithium-ion cells and batteries.



The widespread demand for lithium-ion cells and batteries has given rise to illicit copying to profit through counterfeiting. Counterfeit cells and batteries have become more prevalent today due to the very lucrative business created with the exponentially increasing demand for lithium-ion batteries. Counterfeit cells are manufactured by imitating high-quality and authentic cells and sold at significantly lower costs. This is done to deceive customers into believing that the fake product provides equal or greater performance than the authentic product. These counterfeit products tend to have fake and unauthorized trademarks or logos, making them impossible for customers to differentiate. Counterfeit cells and batteries have low-quality components and are not certified to any standards, which seriously compromises the products' safety, quality, and performance and poses many health and safety risks for customers.

There are plenty of reports on counterfeit or poor-quality cells, and the sale of counterfeit cells and batteries does not always happen on Web sites of dubious origin.[1] There are reports of lithium-ion cells purchased from reputable e-commerce channels that have failed even under "normal" operating conditions.[2] In many of the reported safety incidents, the people affected do not have a recourse because neither the vendors nor the distributors want to be held responsible for any safety incidents.

In the vast worldwide network of cell manufacturers, distributors, sellers, and resellers, it is not easy to confirm authenticity and certification to quality and safety standards. The large volume of cells manufactured and handled makes it challenging to detect poor-quality or counterfeit batteries. On some occasions, the product's sale is carried out maliciously, putting the economic interest of one person or organization before the safety of the equipment and the end-user's health.[3]

QUALITY AND PERFORMANCE OF COUNTERFEIT LITHIUM-ION CELLS AND BATTERIES

Manufacturers of low-quality and counterfeit cells typically lack the technical knowledge, experience, and understanding required for proper quality control, safety, and shipping. The materials used in the cells are often of inferior quality, the cells are poorly designed and assembled, and the cells may contain contaminants.[4] Some unauthorized retailers also purchase poor-quality or aged cells at low prices from other sources and

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deliberately relabel or repackage them under their own brand name or under the brand name of a well-known cell manufacturer.[5] Some of the rewrapped cells have been reported to be cells either rejected or binned as low quality by major cell manufacturers because they did not meet the minimum performance requirements.[5] These properties of counterfeit and repackaged cells directly result in compromised performance, quality, and safety of the battery products and eventually the devices that use them.[5,6]

Significant discrepancies between the advertised and the actual achievable performance may exist in low-quality and counterfeit cells. Some manufacturers of low-quality cells even advertise performances that are outright unachievable by that size and format of cell. Customers unknowingly purchase these items because they appear superior to other similar cells. Noticing these discrepancies may be difficult, because lithium-ion cells are highly variable in terms of geometries and are manufactured with different cathode and anode chemistries that provide varied performance. Application-specific designs of cells mean performances may vary among cells that appear similar. It is crucial to understand the application-based requirements before purchasing or using any type of lithium-ion cells. Counterfeit cells and batteries that are not designed to work with a specific device or tool and charging system could result in overheating and thermal runaway. Experimentally testing performance features such as cell capacity and power can highlight these discrepancies. For example, a cell capacity less than a quarter of the advertised value listed on the label from the manufacturer was experimentally measured for cells purchased online, as shown in Table S1. In this example, the manufacturer's label displayed the cells' capacity at 5000 mAh (which is presently unachievable for an 18650-type cell) while the measured capacity was only 1200 mAh.

In some cases, counterfeit and low-quality cells are easier to spot by carefully examining the labels. Incorrect spellings, modified logos, missing date stamps, and different fonts than the original product may hint at low-quality and counterfeit products.[7] Certifications can also be falsified, along with misleading performance claims on the label showing incorrect testing and certification marks.[8] In many cases, it is challenging to distinguish an authentic certificate or certification mark on a counterfeit product. Hence, caution is warranted when purchasing cells from third-party sellers on online marketplaces and unauthorized resellers.

■ SAFETY OF COUNTERFEIT LITHIUM-ION CELLS AND BATTERIES

Lithium-ion cells may go into failure with excessive release of heat and ejecta as well as fire in some cases when they experience off-nominal conditions or contain manufacturing defects.[9−11] Cell designs, state-of-charge, electrode and electrolyte materials, and the type of abuse conditions affect the level of hazards in such off-nominal events.[9,12] High-quality commercial lithium-ion cells employ various built-in safety mechanisms for protection against off-nominal conditions, such as overcharging and high temperatures as well as external short circuits.[13] In contrast, counterfeit cells often lack these safety mechanisms and are not tested or certified to safety standards. For example, most 18650 lithium-ion cells from reputable cell manufacturers have at least two internal protective devices: a positive temperature coefficient (PTC) and a current interrupt device (CID). These devices are located in the cell header and protect the cells under external short circuit conditions and overcharge events, respectively.[14,15] The PTC consists of a thin, electrically conducting polymer layer between two flat metal rings. If an external short occurs, the high current flowing through the PTC causes the polymer to heat and its resistance to rise sharply, reducing the current flowing through the cell.[16] The CID consists of two metal disks that are in electrical contact only at the center, which also provides the electrical contact between the electrode and the cell terminal.[14] During overcharging, gas production inside the cell causes pressure build-up, which activates the CID and disconnects the electrical pathway.[17] If the pressure still increases within the cell, the excess pressure is released in a controlled manner through vent holes in the top cover. Apart from the PTC and CID, some cells have additional protective devices such as bottom vents and external protective circuit boards.[18]

> Low-quality and counterfeit cells may be unsafe due to lack of relevant protective controls typically found inside authentic cells.

At the battery level, safety mechanisms including the battery management system (BMS) are used to protect batteries against off-nominal conditions. Counterfeiters may lack the knowledge to design a proper BMS, or the cells in the battery may be improperly balanced. Bad design practices and poorly made welds within counterfeit batteries have also been reported.[19] At the system level, which consists of the battery, the electronic device, and the charger, there are no guarantees that the components in counterfeit products are designed and tested to work together. This can result in poor performance, shorter life, damage to the device and charger, and in the worst case thermal runaway in the battery, leading to personal injury and/or property damages.[20]

The ubiquity of lithium-ion cells and a lack of public education and awareness regarding proper disposal and recycling methods have contributed to a surge in fires in waste sorting and recycling facilities around the world.[21,22] Lithium-ion batteries that end up in general waste have been deemed as the cause of fire incidents in many recycling and waste facilities. Demand growth for batteries and resource scarcity along with improvements in recycling technologies have led to increased interest in battery recycling.[23] Battery failure may occur during transportation, storage, or operation, and the likelihood and severity of hazards may be exacerbated if the quality of the cells is inferior. Transport regulations and guidelines for shipping battery materials could be circumvented by traders of counterfeit batteries by shipping the hazardous batteries as undeclared goods. Counterfeit cells that do not meet safety requirements based on existing standards may pose safety risks during recycling steps, including discharging and dismantling, and any inferior material quality may add further separation steps to remove impurities.

In the present work, the compromise in safety with low-quality and counterfeit batteries is studied using 18650 cells. A literature review on the performance and safety of low-quality and counterfeit lithium-ion batteries returned zero results, indicating a lack of studies in this area. This study aims to show the response of high-quality and counterfeit batteries under two off-nominal conditions, namely, overcharge and external short, and describe how those results can be used to detect

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counterfeit cells to enable safer battery choices for various applications. Early results from our research group showed that the internal configuration of the cell could affect the cell response during failure. For that reason, a destructive physical analysis was performed on the cells and protective devices embedded in the header of the cells.

■ CELL CAPACITY AND PHYSICAL DESCRIPTION

Cells from manufacturers A and B looked similar when inspected visually and were sold under the same brand names and specifications.[9] The rated capacity for these cells was 3200 mAh. The discrepancies in manufacturer rated capacity and measured capacity were evident only upon validation tests, Table S1. Manufacturer A provided the capacity specified on the label, and manufacturer B provided less than half of the specified capacity. Manufacturer C claimed to have a capacity of 5000 mAh, although the maximum capacity found in the market for the 18650 lithium-ion cell design from reliable manufacturers is 3400 mAh. Upon testing, manufacturer C provided only a quarter of the capacity they claimed, at 1200 mAh. The capacity measured in the cells indicates the poor performance of low-quality cells. However, the response of the cells to off-nominal test conditions is even more relevant for safety reasons. Cells from manufacturer A were nominally priced and had a longer time for procurement of 6 to 8 weeks. Cells from manufacturers B and C were inexpensive, at a fraction of the cost of the high-quality manufacturer A cells, and could be purchased online with a turnaround time of less than a week.

> Visual inspection may not always confirm authenticity of lithium-ion cells.

Some low-quality manufacturers change the outer labels for their cells. Manufacturer C had a yellow outer label for cells procured in 2016 (Figure S1a) with height greater than 65 mm (the 18650 cell has a diameter of 18 mm and a height of 65 mm). Removal of the label and opening of the cell showed the presence of an 18650 cell (blue cell in Figure S1a) inside the can, with a protective circuit board attached to the header area. The outer (yellow) label displayed a cell capacity of 5000 mAh, and the label on the blue cell within showed the cell capacity as 1300 mAh, while the actual capacity measured from tests on the cells was much lower, at 600 mAh. Overcharge tests of the 18650 cell after removing the external circuit board resulted in a catastrophic failure, indicating the absence of the CID that provides protection in this cell format.

A visual inspection of the cells from manufacturers A and B showed only subtle differences in the header area of the cell that might go unnoticed by someone unfamiliar with the cell structure (Figure S1b). Cells from manufacturer C procured along with those from manufacturers A and B had the same dimensions as any 18650 cell. All test results discussed in this manuscript refer to cells procured in 2020.

■ DESTRUCTIVE PHYSICAL ANALYSIS

Fresh cells from each manufacturer were subjected to a destructive physical analysis (DPA) to investigate further differences in the cell internal structure, Figure 1. The first difference between the cells was found by removing the plastic wrap. The cell can from manufacturer A had a shiny finish, while the cell from manufacturer B had a dull finish. The cell from manufacturer C included a second transparent plastic wrap below the outer plastic label. The cell can and header were removed, and the jelly roll was exposed (see Figure 5b, below). Manufacturer A had two thick plastic insulators at the top (brown) and bottom (blue) of the cell to prevent shorting with the tab and cell can. The jelly roll was held together with the red tape placed axially and radially. Manufacturer B had only a thin plastic insulator at the top (white). The jelly roll was held with the green tape placed axially. Manufacturer C had no plastic insulator, and the jelly roll did not have any tape. Although the width of the separator was long enough to prevent electrode contact, it is not possible to know if the added separator width is a design issue or was coincidental. A central mandrel was found only with cells from manufacturer A. This metal rod provides mechanical support and directs the gases produced within the cell during off-nominal conditions.

The lengths of electrodes and separators are listed in Table S1. For manufacturer A, the length of the electrode was normal for its capacity. The cathode was identified as NCA (nickel−cobalt−aluminum oxide), and the separator had an alumina (Al_2O_3) coating on the side facing the cathode. For manufacturer B, the length of the electrode was longer than for manufacturer A but with almost half the cell capacity as manufacturer A. The cathode was identified as NMC (nickel−manganese−cobalt oxide) with low cobalt content, and the separator did not have any coating. For manufacturer C, the length of the electrode was much shorter than for either of the other two manufacturers. The cathode was identified as LMO (lithium−manganese oxide), and traces of silicon were found on the anode. The details of the cathode chemistry and the separator are provided only to show that, although manufacturers A and B had identical manufacturer names and details on the labels regarding capacities and model numbers, the chemistries and the length of the electrodes were, in fact, different.

■ MORPHOLOGY

Analysis of the electrodes and separator morphology extracted from fresh cells provided further clarity on the quality differences among different manufacturers. Figure 2 shows a comparison of the cathode, separator, and anode micrographs from manufacturers A (panels a−c), B (panels d−f), and C (panels g−i). Homogeneous active material distribution, forming a porous electrode framework, was observed for manufacturer A, Figure 2a. In the case of the low-quality manufacturers, nonuniform distribution, with large agglomerates of active material and binder, were noticeable, Figure 2d,g, along with the formation of dough-like structures. These agglomerates may be formed due to a bad manufacturing process. Comparison of the surface morphology of the separators exhibited a clearly aligned network of micropores for manufacturer A, Figure 2b, in addition to the alumina-coated layer on the other side, Figure S2. The two sides of the separators were similar for the other manufacturers, without the presence of the protective alumina layer, and had a highly unusual structure, with almost nonporous regions for manufacturer B, Figure 2e, and nonuniform distribution and lower porosity for manufacturer C, Figure 2h. Anodes from manufacturer B showed cracks and nonuniform surface morphology that are unusual for electrodes from fresh commercial-grade cells, Figure 2i. Furthermore, electrodes

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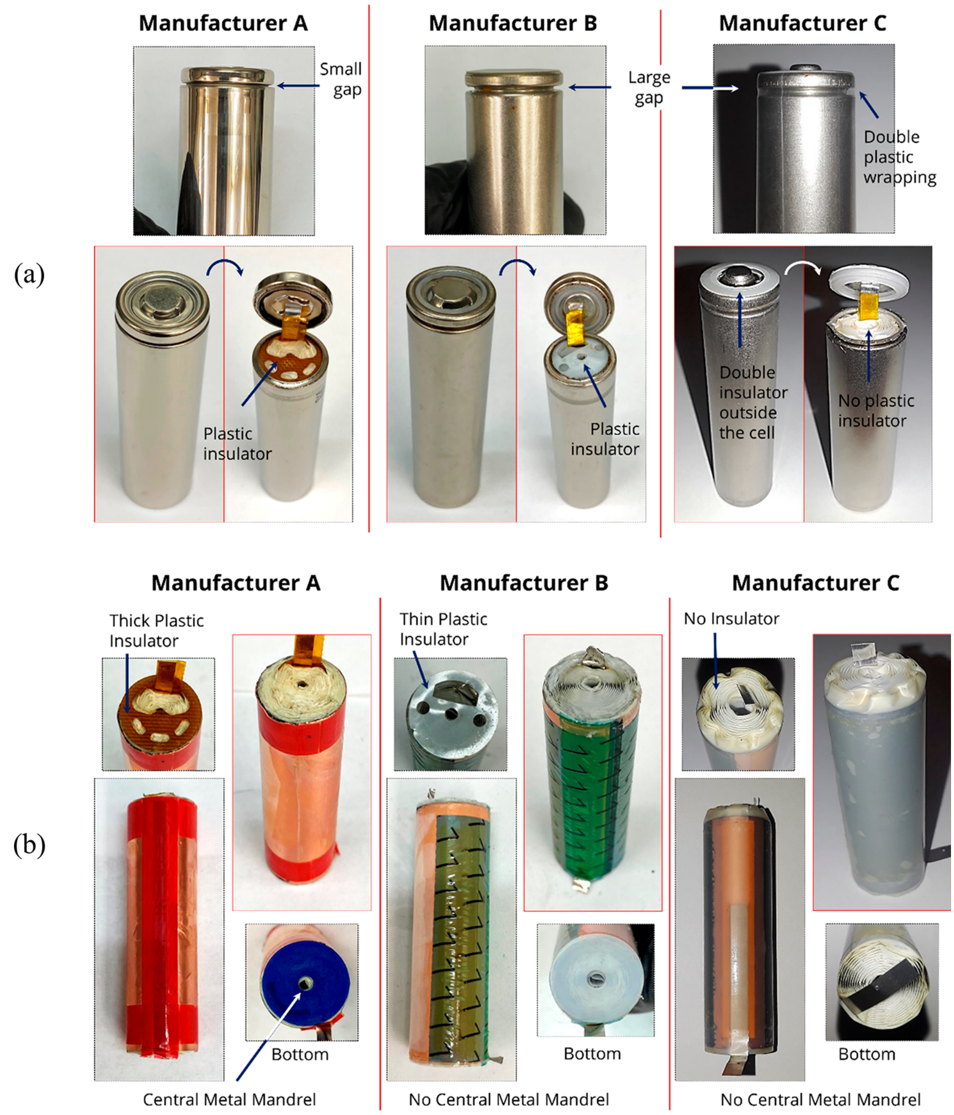

Figure 1. Destructive physical analysis of test samples. (a) Cells after plastic label removal. (b) Exposure of jelly roll after cell can removal.

from manufacturers B and C exhibited severe delamination of the active material from the current collector.

CELL PROTECTIONS

Destructive physical analysis of the cell header was performed to investigate the included protection devices, Figure 3. The cells from the original cell manufacturer contained the PTC and CID for protection against external shorts and overcharge, respectively, Figure 3a. In contrast, neither low-quality cell contained these protective devices, significantly compromising safety, Figure 3b,c. Inthe cell from manufacturer B, rust was observed in the space between the crimp area of the can and the gasket. The poor quality of the seals may have caused an electrolyte leak, which rusted the cell can.

OVERCHARGE TEST

The overcharge test demonstrated the effectiveness of cell safety features and protections offered by the CID against overcharge conditions. When a cell is charged beyond its manufacturer-recommended voltage limit, the capability of the anode to accommodate lithium ions is exceeded, leading to deposition of lithium metal on its surface and a reduction in thermal stability.[24,25] In addition to this, cathode destabilization with release of oxygen and high temperatures are experienced. Cells with the CID offered protection against overcharge, as in the case of cells from manufacturer A. The increase in the internal pressure of the cell due to the formation of gases with the intentional addition of Li_2CO_3 activates the CID and breaks the internal electrical connection to the electrodes, thus preventing further overcharge and keeping the cell from going into a thermal runaway, Figure 4a,e.[13] The temperature of the cell from manufacturer A remained below 80 °C during the overcharge test. In the cases of cells from manufacturers B and C in Figure 4b−d and f−h, without the protection available from the CID, the cells continue to heat, with a breakdown in thermal stability leading to thermal runaway. Two overcharge tests were conducted on the cells from manufacturer B using the actual capacity (1870 mAh), Figure 4b,f, and rated capacity (3200 mAh), Figure 4c,g. Cells from manufacturer B overcharged at 1.8 A (1C rate based on actual measured capacity) reached a maximum temperature of 140 °C and electrolyte leakage was observed, Figure 4b,f. When the cells from manufacturer B were overcharged with a 1C current of 3.2 A, using the rated

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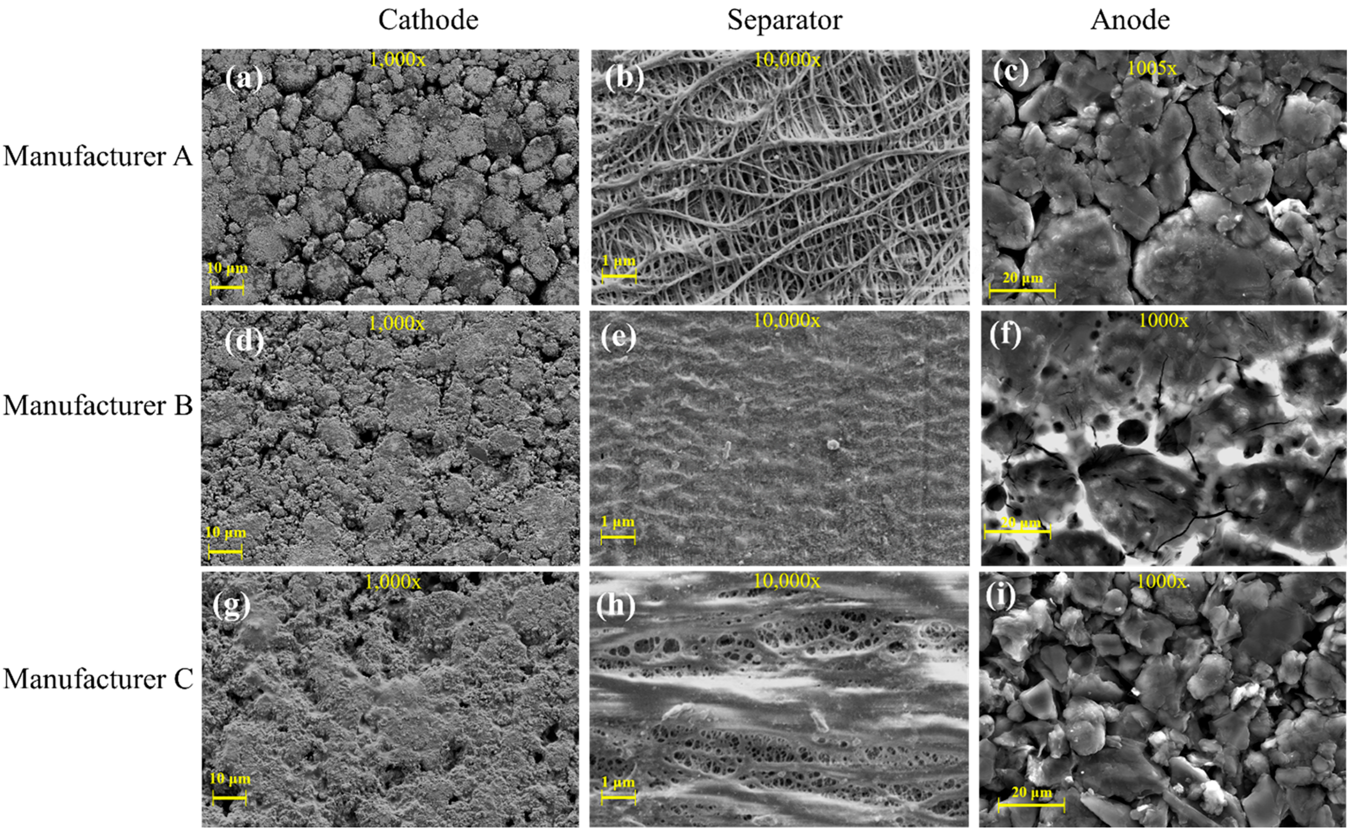

Figure 2. SEM micrographs of cathode, separator, and anode extracted from fresh cells from manufacturers A (a−c), B (d−f), and C (g−i).

capacity of 3.2 Ah as depicted on the cell label, the maximum temperature reached was roughly 600 °C, with ejection of sparks and charring observed, Figure 4c,g. For the cells from manufacturer C, the overcharge test current of 1.2 A (1C current based on actual measured capacity) was used, and the maximum temperature observed was 110 °C. Temperatures stopped increasing when the cell went into thermal runaway with ejection of jellyroll, Figure 4h.

Figure 4e−h shows a comparison of the post-overcharge test pictures for cells from all manufacturers. The wires attached to the cells were used to tether the cells and prevent them from being projectile hazards in case of a blowout. High-quality cells did not experience hazards such as extreme heating, electrolyte leakage, fire, and thermal runaway under the off-nominal condition of overcharge, as observed in the cells from manufacturer A, Figure 4e. Lack of protection typically offered by the CID renders cells from manufacturers B and C prone to these hazards. Electrolyte leakage, overheating, fire, and thermal runaway were observed for manufacturer B and C cells, Figure 4f,h.

■ EXTERNAL SHORT TEST

Figure 5a−c compares fully charged cells from manufacturers A, B, and C when an external short of 10 mΩ was applied across the cells, and the post-test pictures of the cells are shown in Figure 5d−f. The cell voltage drops immediately, and the current reaches the maximum value with the application of external short followed by a stabilization period. The cell temperature continues to rise and may lead to uneven or localized heating in cells. Cells with PTC devices in the header, as in the case of cells from manufacturer A, offer protection in such scenarios by limiting the excessive current experienced by the cell by increasing the resistance of the PTC device, Figure 5a,d. The maximum temperature reached by the cell from manufacturer A was 56 °C, with no external damage. Without such protection, the high heat sustained in the cell can cause overheating, venting with smoke, release of hot liquid electrolyte, and cell rupture, as observed in the case of cells from manufacturer B, Figure 5b,e. The maximum temperature reached by the cell from manufacturer B was 144 °C, with partial ejection of its content. In worst-case scenarios, explosion of the cell and ejection of the jellyroll may occur, as evidenced in the case of cells from manufacturer C, Figure 5c,f. The maximum temperature recorded for the cells from manufacturer C was 167 °C.

> Low cost and quick delivery of lithium-ion cell procurements may indicate low quality or counterfeit products.

In the present work, cells from three manufacturers (A, B, and C) were studied to gain knowledge on counterfeit cells and batteries. Manufacturer B had the same label and manufacturer's name as manufacturer A, and manufacturer A was the original manufacturer. Counterfeit cells (manufacturers B and C) provided less than half of their rated capacity. Manufacturer A provided the capacity indicated on the cell label. The physical analysis and DPA of the cells revealed that counterfeit cells did not have PTC and CID protective devices. Poor-quality electrodes and separators were also evident from SEM analysis for manufacturers B and C. The separator from the high-quality cell had a ceramic coating to prevent internal short circuit. Under off-nominal conditions, the high-quality

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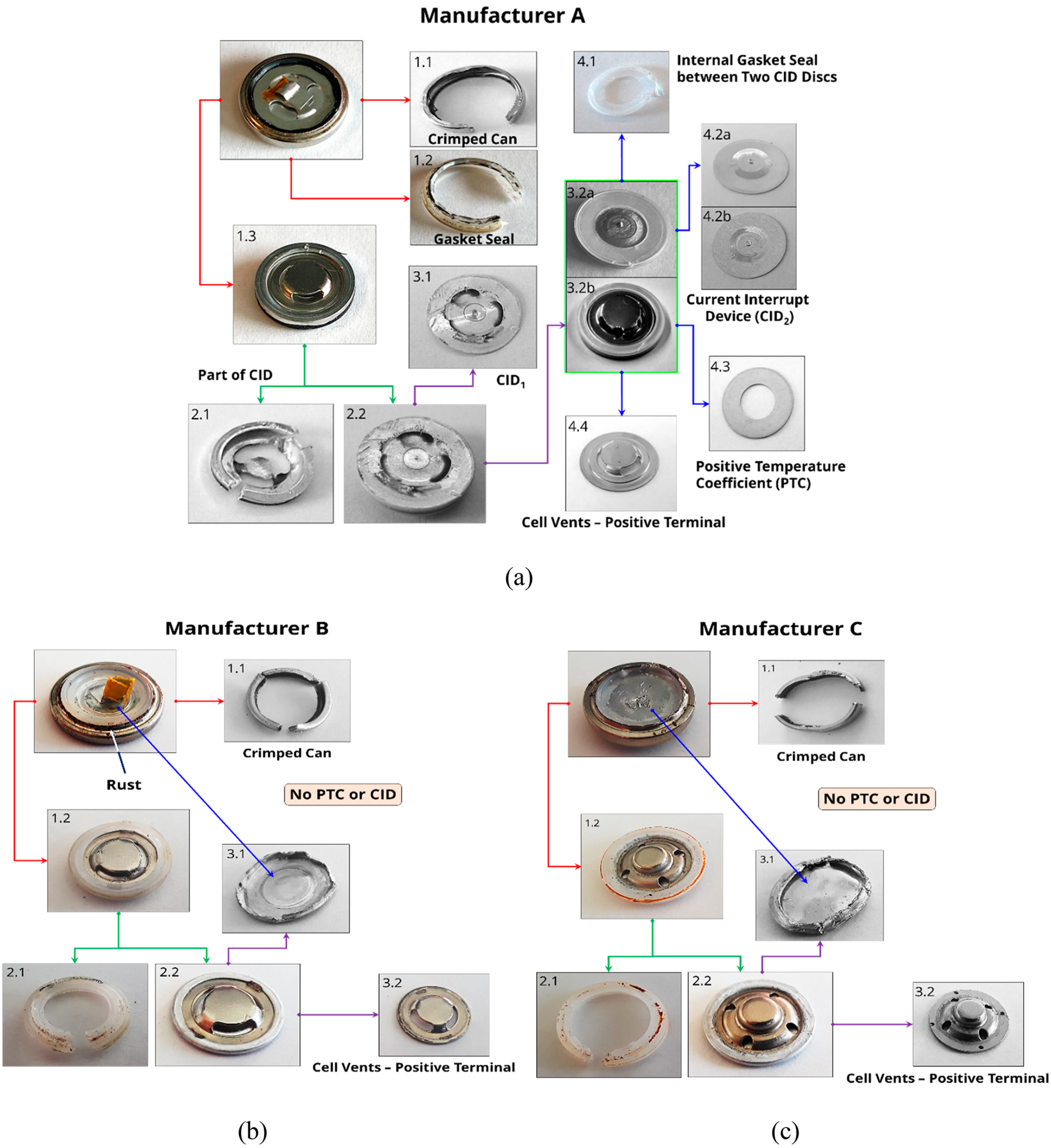

Figure 3. Destructive physical analysis of test samples. Photographs of the header parts of cells from (a) manufacturer A (original cell manufacturer), (b) manufacturer B (counterfeit), and (c) manufacturer C (low quality).

cell did not exhibit external damage or overheat. On the other hand, the low-quality cells from manufacturers B and C underwent thermal runaway, experiencing electrolyte leakage, extreme overheating, and fire. The catastrophic response from these cells is due to the absence of protective devices and the low-quality manufacturing.

Knowledge of the cell models and relative capacities that can be obtained with commonly found commercial cell models/designs is required to tell if a cell is overrated. Physical, electrochemical, and materials characterization will provide further confirmation on the quality of the cells and batteries. Off-nominal tests such as overcharge and external shorts can provide the information needed to confirm any cell designs suspected as counterfeit. Since all of these tests required specialized equipment and knowledge not available for everyone, some recommendations on avoiding counterfeit batteries are presented here.

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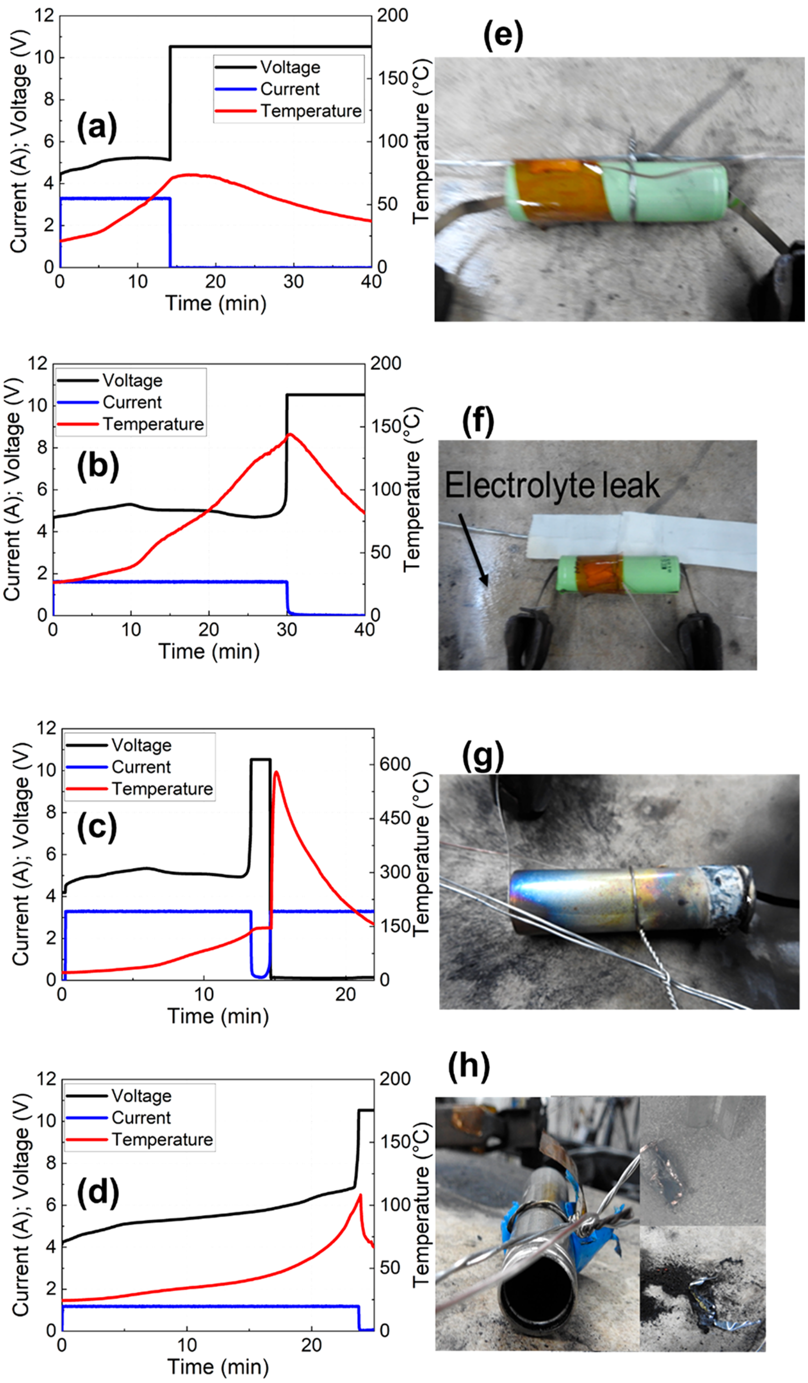

Figure 4. Overcharge tests on cells from manufacturer A (a, e), manufacturer B (b, f, measured 1C-current, and c, g, rated 1C-current), and manufacturer C (d, h, measured 1C-current). (a–d) Electrochemical and thermal results and (e–h) photos of the cells after the overcharge test.

■ CONSIDERATIONS FOR DETECTING AND AVOIDING COUNTERFEIT LITHIUM-ION BATTERIES

Counterfeit products may be difficult to distinguish from authentic and high-quality products. The first step in ensuring the high quality and authenticity of cells is to purchase from reputable manufacturers and authorized suppliers. Some low-quality or counterfeit cells mimicking high-quality or authentic cells may be identifiable by physical examination, whereas others may need more specialized testing. Therefore, whenever possible, validation tests must be conducted on cells before use in consumer devices or other end applications to ensure that quality and performance requirements adhere to the application targets and manufacturer specifications. Verification of claims made by manufacturers on cell performance may not be easy to perform because it often requires specific instrumentation not readily available to everyone. However, the following guidelines may be useful in detecting counterfeit products:

1. Visual inspection to look for signs of poor quality, such as inaccurate printing, misspelled wording, crooked label placement, and signs of defective workmanship.

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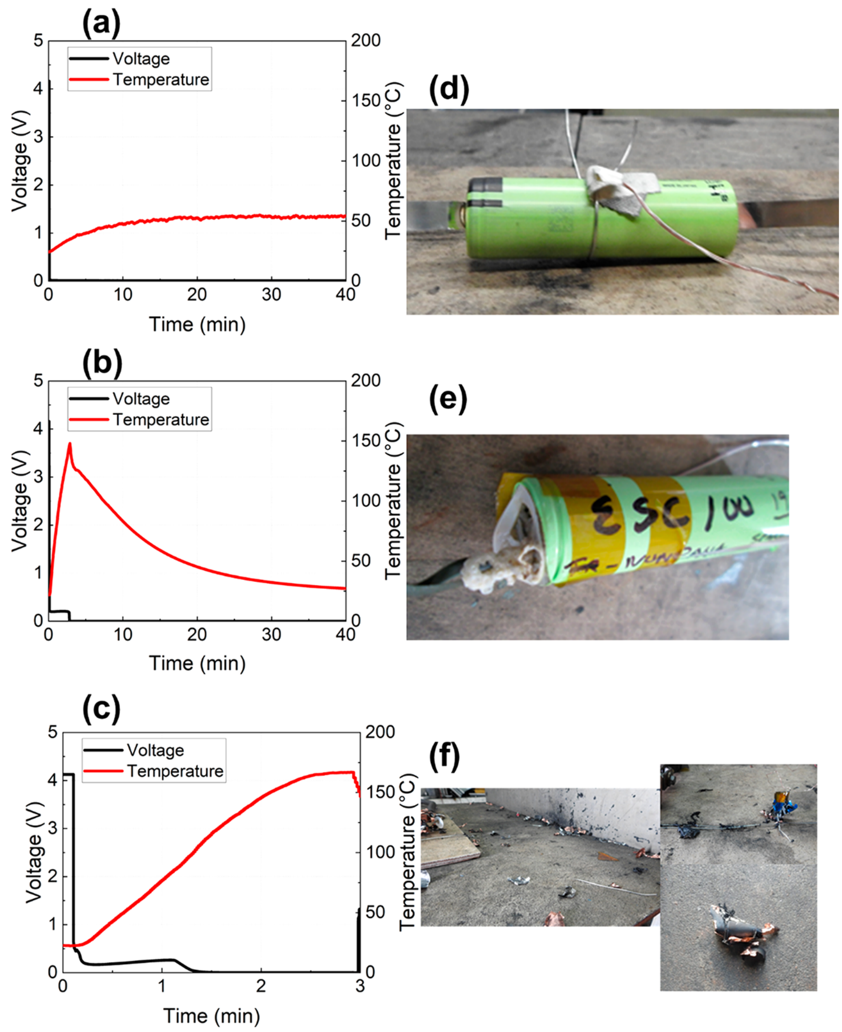

Figure 5. External short tests on cells from manufacturer A (a, d), manufacturer B (b, e), and manufacturer C (c, f). (a–c) Electrochemical and thermal results and (d–f) photos of the cells before and after the test.

2. Recognizing inappropriate or fake certification labels on the cells and batteries.
3. Being vigilant of significantly reduced price in comparison with similar authentic products.
4. Quick delivery of procurement. Cells from high-quality manufacturers typically have longer lead times and are not delivered within a week.
5. After procurement of cells, measuring the cell voltage, weight, dimensions, capacity, and internal resistance and comparing with datasheets available through original manufacturers may be useful.

Precautions must be taken during purchase to avoid counterfeit products. Some easy-to-follow considerations may help avoid risks:

1. Purchase only from the original equipment manufacturer (OEM) or from reputable retailers and suppliers recommended by the OEM.
2. Check every detail of the product, as described above, to detect and avoid counterfeit products.
3. Whenever possible, ask the vendor for pictures of the actual products. Compare the trademark and the logo with the authentic ones.
4. Verify that the certification label is authentic.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsenergylett.3c00724.

Experimental details, cell specifications, test descriptions, photographs of cells, SEM micrographs, and additional references (PDF)

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Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) Kong, L.; Das, D.; Pecht, M. G. The Distribution and Detection Issues of Counterfeit Lithium-Ion Batteries. *Energies* **2022**, *15* (10), 3798.
(2) Semueals, A. When Your Amazon Purchase Explodes. *The Atlantic*, Apr 30, 2019.https://www.theatlantic.com/technology/archive/2019/04/lithium-ion-batteries-amazon-are-exploding/587005/ (accessed April 26, 2023).
(3) Taylor, P. LA Man Pleads Guilty to Massive Fake Laptop Battery Scam. *Securing Industry*, Jun 30, 2021.https://www.securingindustry.com/electronics-and-industrial/la-man-pleads-guilty-to-massive-fake-laptop-battery-scam/s105/a13640/#.Yh8PZehKiHu (accessed April 26, 2023).
(4) Mikolajczak, C.; Harmon, J.; White, K.; Horn, Q.; Wu, M. Detecting lithium-ion cell internal faults in real time. *Electronic Design*, Mar 1, 2010. https://www.electronicdesign.com/markets/mobile/article/21191978/detecting-lithiumion-cell-internal-faults-in-real-time (accessed March 20, 2022).
(5) Saxena, S.; Kong, L.; Pecht, M. G. Exploding E-Cigarettes: A Battery Safety Issue. *IEEE Access* **2018**, *6*, 21442−21466.
(6) ICE HSI arrests Chinese National in $23.8 Million Scheme to Sell Counterfeit Laptop Computer Batteries on eBay and Amazon. U.S. Immigration and Customs Enforcement, Dec 19, 2019. https://www.ice.gov/news/releases/ice-hsi-arrests-chinese-national-238-million-scheme-sell-counterfeit-laptop-computer (accessed February 26, 2022).
(7) FBI Los Angeles Field Office. Counterfeit and Substandard Lithium Batteries Pose Serious Health Risks to Law Enforcement. Federal Bureau of Investigation Intelligence Bulletin, June 7, 2012.
(8) UL Warns of Li-Ion Batteries with Counterfeit UL Mark, Release 12PN-59. UL Solutions, Dec 17, 2012. https://www.ul.com/news/ul-warns-counterfeit-ul-mark-battery-release-12pn-59 (accessed February 26, 2022).
(9) Joshi, T.; Azam, S.; Lopez, C.; Kinyon, S.; Jeevarajan, J. Safety of Lithium-Ion Cells and Batteries at Different States-of-Charge. *J. Electrochem. Soc.* **2020**, *167* (14), 140547.
(10) Longchamps, R. S.; Yang, X.-G.; Wang, C.-Y. Fundamental Insights into Battery Thermal Management and Safety. *ACS Energy Lett.* **2022**, *7* (3), 1103−1111.
(11) Jeevarajan, J. A.; Joshi, T.; Parhizi, M.; Rauhala, T.; Juarez-Robles, D. Battery Hazards for Large Energy Storage Systems. *ACS Energy Lett.* **2022**, *7* (8), 2725−2733.
(12) Huang, W.; Feng, X.; Han, X.; Zhang, W.; Jiang, F. Questions and Answers Relating to Lithium-Ion Battery Safety Issues. *Cell Rep. Phys. Sci.* **2021**, *2* (1), 100285.
(13) Juarez-Robles, D.; Azam, S.; Jeevarajan, J.; Mukherjee, P. P. Degradation-Safety Analytics in Lithium-Ion Cells and Modules Part II. Overcharge and External Short Circuit Scenarios. *J. Electrochem. Soc.* **2021**, *168* (5), 050535.
(14) Xu, B.; Kong, L.; Wen, G.; Pecht, M. Protection Devices in Commercial 18650 Lithium-Ion Batteries. *IEEE Access* **2021**, *9*, 66687−66695.
(15) Juarez-Robles, D.; Jeevarajan, J. A.; Mukherjee, P. P. Degradation-Safety Analytics in Lithium-Ion Cells: Part I. Aging under Charge/Discharge Cycling. *J. Electrochem. Soc.* **2020**, *167* (16), 160510.
(16) Jeevarajan, J. Safety of Commercial Lithium-Ion Cells and Batteries. In *Lithium-Ion Batteries*; Pistoia, G., Ed.; Elsevier: Amsterdam, 2014; pp 387−407.
(17) Juarez-Robles, D.; Vyas, A. A.; Fear, C.; Jeevarajan, J. A.; Mukherjee, P. P. Overcharge and Aging Analytics of Li-ion Cells. *J. Electrochem. Soc.* **2020**, *167* (9), 090547.
(18) Xu, B.; Kong, L.; Wen, G.; Pecht, M. G. Protection Devices in Commercial 18650 Lithium-Ion Batteries. *IEEE Access* **2021**, *9*, 66687−66695.
(19) Tichy, R. The Dangers Of Counterfeit Battery Packs: Answers To Reader Questions. Electronic Design, Oct 22, 2008. https://www.electronicdesign.com/power-management/article/21778315/the-dangers-of-counterfeit-battery-packs-answers-to-reader-questions (accessed March 16, 2022).
(20) Use Original Power Tool Manufacturer Batteries - Avoid the Hazards of Knock-Off and Counterfeit Batteries. Power Tool Institute, Inc., Spring 2020. https://www.powertoolinstitute.com/pti-pages/it-original-power-tool-batteries.asp (accessed March 16, 2022).
(21) Chen, Z.; Yildizbasi, A.; Wang, Y.; Sarkis, J. Safety Concerns for the Management of End-of-Life Lithium-Ion Batteries. *Global Challenges* **2022**, *6* (12), 2200049.
(22) Mikalsen, R. F.; Lönnermark, A.; Glansberg, K.; McNamee, M.; Storesund, K. Fires in waste facilities: Challenges and solutions from a Scandinavian perspective. *Fire Safety J.* **2021**, *120*, 103023.
(23) Baum, Z. J.; Bird, R. E.; Yu, X.; Ma, J. Lithium-Ion Battery Recycling—Overview of Techniques and Trends. *ACS Energy Lett.* **2022**, *7* (2), 712−719.
(24) Zhao, C.; Wang, T.; Huang, Z.; Wu, J.; Zhou, H.; Ma, M.; Xu, J.; Wang, Z.; Li, H.; Sun, J.; Wang, Q. Experimental Study on Thermal Runaway of Fully Charged and Overcharged Lithium-Ion Batteries Under Adiabatic and Side-Heating Test. *J. Energy Storage* **2021**, *38*, 102519.
(25) Feng, L.; Jiang, L.; Liu, J.; Wang, Z.; Wei, Z.; Wang, Q. Dynamic overcharge investigations of lithium ion batteries with different state of health. *J. Power Sources* **2021**, *507*, 230262.

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