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A State of Charge Analysis of 12 Lithium Ion Batteries (12.8 Volt) Previously Shipped on Aircraft

September, 2024

Technical Note

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16. Abstract

The transportation of lithium batteries is heavily regulated. UN 3480, lithium-ion batteries (batteries not packed with or contained within equipment) are forbidden on passenger aircraft and cannot exceed 30% state of charge (SoC) when transported on cargo aircraft.

In March 2024, two packages containing lithium-ion cells (UN3480) started to smolder while being loaded into a unit load device (ULD) at the Hong Kong International Airport. An investigation determined that numerous cells within both packages showed significant signs of charring. Other packages from this shipping account had arrived at its destination airport in Ontario, California.

A team of hazardous materials aviation safety inspectors from the Federal Aviation Administration (FAA)'s Office of Hazardous Materials Safety (AXH) inspected the packages on-site in California. Subsequently, AXH contacted the FAA's Fire Safety Branch to aid in further analysis. Twelve batteries were sent to the Fire Safety Branch at the William J. Hughes Technical Center, where testing was performed to determine the as-delivered SoC. Findings determined that the average SoC of the twelve lithium-ion batteries was 49.2%.

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Acronyms

Acronym	Definition
(4s2p)	4 series 2 parallel
A	Amps
Ah	Ampere-hour
CC	Constant Current
CV	Constant Voltage
FAA	Federal Aviation Administration
SoC	State of Charge
ULD	Unit Load Device
V	Volts
Wh	Watt-Hour

Executive summary

The transportation of lithium batteries is heavily regulated. UN 3480, lithium-ion batteries (batteries not packed with or contained within equipment), are forbidden on passenger aircraft and cannot exceed 30% state of charge (SoC) when transported on cargo aircraft.

In March 2024, two packages containing lithium-ion cells (UN3480) started to smolder while being loaded into a unit load device (ULD) at the Hong Kong International Airport. An investigation determined that numerous cells within both packages showed significant signs of charring. Other packages from this shipping account had arrived at their destination airport in Ontario, California.

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1 Introduction

The transportation of lithium batteries is heavily regulated. Lithium batteries have contributed to the spread of fire and may have been an ignition source for numerous catastrophic in-flight fires that occurred in the late 2000s. As a result of this hazard, domestic and international regulations require UN 3480 lithium-ion batteries (batteries not packed with or contained within equipment) to be below 30% state of charge (SoC) when transported on cargo aircraft (Lithium cells and batteries, 2024). Past testing has shown that lithium batteries above 30% SoC are a substantial fire hazard and can lead to unsafe conditions on an aircraft. In the event of thermal runaway, heat is much more likely to propagate to nearby cells and cargo at an elevated SoC (Webster, et al., 2016; Maloney, 2016; Maloney, 2022).

In March 2024, two packages containing lithium-ion cells (UN3480) started to smolder while being loaded into a unit load device (ULD) at the Hong Kong International Airport. An investigation determined that numerous cells within both packages showed significant signs of charring. Other packages from this account had arrived at its destination airport in Ontario, California.

A team of aviation safety inspectors from the FAA’s Office of Hazardous Materials Safety (AXH) inspected the packages on-site in California. Subsequently, AXH contacted the FAA’s Fire Safety Branch to aid in further analysis. Twelve batteries were sent to the Fire Safety Branch at the William J. Hughes Technical Center, where testing was performed to determine the as-delivered SoC of the batteries.

2 Test setup

Twelve 1715 Watt-hour (Wh) batteries with outer dimensions of 10.0 by 8.5 by 6.5 inches were delivered to the Fire Safety Branch (Figure 1). The batteries were visually inspected upon arrival to find relevant charging specification information. Values such as the nominal voltage, maximum charging voltage, and rated capacity were marked clearly on the exterior of the battery (Table 1, shaded rows). However, other information such as the constant voltage (CV) termination current and the minimum discharge voltage were not specified. Online web searches and direct correspondence with the battery manufacturer could not provide this information, so values from other batteries of the same cathode chemistry ($LiFePO_4$) were used (Table 1, rows in white).

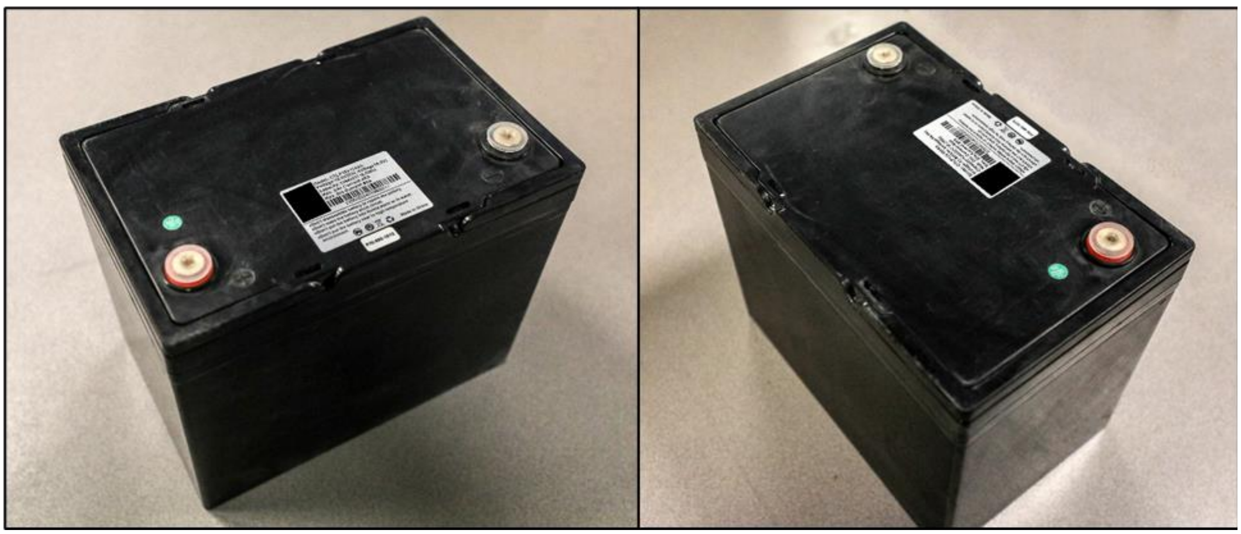

Figure 1. Exterior of the 12.8V (nominal voltage) lithium-ion batteries

Charging parameters used in the testing are shown in Table 1.

Table 1. Charging parameters used

Charging Parameter	Value
Nominal Voltage	12.8 V
Rated Capacity	134 Ah
Rated Energy Capacity	1715 Wh
Constant-Current Charge/Discharge Rate (0.2C)	26.8 A
Max Charge Voltage	14.4 V
Constant-Voltage Termination Current	13.4 A
Minimum Discharge Voltage	10.0 V

After testing was completed, one battery was disassembled (Figure 2) to help verify information that was previously presumed. The disassembly determined that eight cells were electrically connected and configured in a 4 series 2 parallel (4s2p) connection. Based on visual observation, the cells appeared to be of the prismatic type.

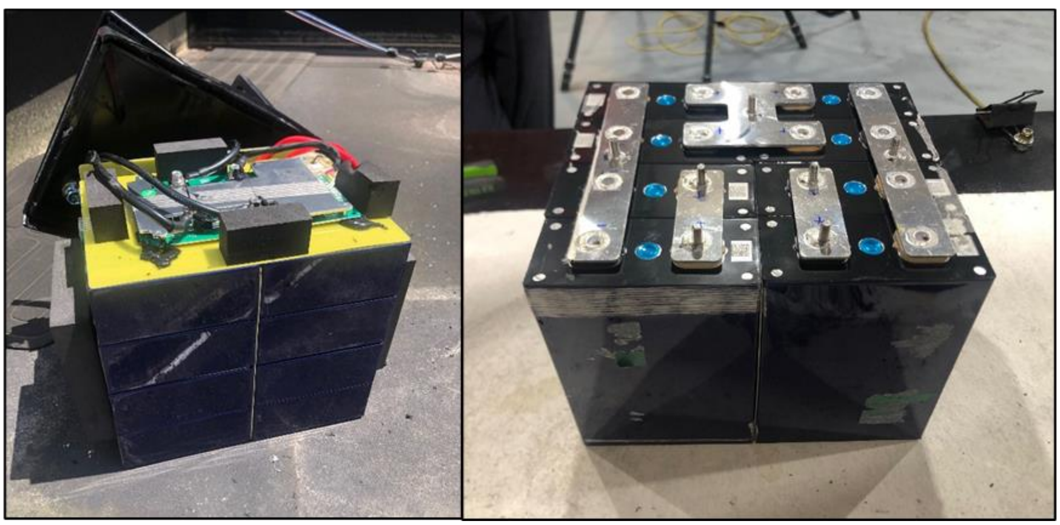

Figure 2. Disassembled battery

SoC testing was conducted using a Chroma 17020 Battery Test System, which has a full-scale range of 0-100 Volts (V) and 0-100 Amps (A). The system can accurately measure voltage within 0.02% of the full-scale voltage, plus 0.02% of the current voltage reading. Furthermore, it can accurately measure current within 0.05% of the full-scale current range, plus 0.1% of the current amperage reading. Based on the charging specifications used within this study, the charger could accurately measure within ± 0.023 V and ± 7.68 mA of the actual values throughout the process.

To calculate SoC, batteries were charged to full capacity and subsequently discharged completely. Batteries were charged utilizing a constant current constant voltage (CC-CV) charging method, which is typical for lithium-ion chemistries. During this process, the total charge capacity and discharge capacity (Ah) were measured and recorded by the test system. From these values, the as-delivered SoC was calculated using Equation 1 below.

$$SoC = \frac{(Total\ Capacity - Charge\ Capacity)}{Total\ Capacity} \tag{1}$$

Based on the methodology described within this test report, the discharge capacity is equivalent to the total capacity, as cells were discharged from 100% to 0% SoC.

Two parameters are pertinent in measuring SoC; C-rate and ambient temperature. C-rate is the charging or discharging current divided by the total capacity (MIT Electric Vehicle Team, 2008). Higher C-rates often lead to the loss of energy to heat, which reduces the measured capacity of the cell. Furthermore, the ambient temperature also affects the measured capacity of the cell. Extreme temperatures, both high and low, will degrade the performance of lithium-ion batteries (Ma, et al., 2018). As a result, it is generally recommended that these variables be controlled when accounting for SoC.

All batteries were stored within a steel-framed fire box which was kept at room temperature (68 ±10 °F) throughout the entirety of the test. Furthermore, a C-rate of 0.2C was used throughout both the charge and discharge process. These values are often used by battery manufacturers and standards organizations for SoC evaluations.

3 State of charge (SoC) results

Calculated from the methodology described above, SoC results for the 12 evaluated batteries are shown below in Table 2.

Table 2. SoC results for each battery

Battery #	Charge Capacity (Ah)	Discharge Capacity (Ah)	As-Delivered SoC
1	67.2	131.1	48.7%
2	66.4	130.9	49.3%
3	66.1	130.1	49.2%
4	67.4	132.1	49.0%
5	66.5	131.1	49.3%
6	66.6	131.3	49.3%
7	66.7	131.3	49.2%
8	66.5	131.5	49.4%
9	66.8	131.4	49.1%
10	66.8	131.1	49.0%
11	67.0	132.0	49.2%
12	66.7	131.0	49.1%

All 12 batteries were found to exceed the required 30% threshold. The average SoC of all twelve batteries was found to be 49.2%. The variance between batteries was minimal, as the SoC of all evaluated batteries was found to be within ±0.5% of the calculated average.

4 Conclusions

Numerous FAA tests have demonstrated that lithium-ion cells and batteries that exceed 30% SoC create an unsafe environment when transported in bulk on aircraft. Batteries that exceed this threshold are likely to propagate heat to nearby cells and cargo in the event of thermal runaway. Results within this study indicate that the twelve batteries delivered to the Fire Safety Branch at the William J. Hughes Tech Center for analysis were at a SoC of 49%.

5 References

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