Transport Canada Transports Canada

Research Summary – Evaluation and Analysis of Substandard Lithium-Ion Batteries by UN 38.3 Testing

Transportation of Dangerous Goods | Scientific Research Division

BACKGROUND

Lithium-ion batteries (LiBs) are used as lightweight, long-lasting energy storage solutions. LiBs are also classified as a Class 9 dangerous good, and LiBs that are damaged, mishandled, or defective can start a fire. These fires are especially hazardous during air transport, as extinguishing these LiBs fires can be very difficult.

To minimize hazards that might occur during transportation by all modes, including air, the transportation of LiBs in Canada is regulated under the *Transportation of Dangerous Goods Regulations* (TDGR). The TDGR requires that LiBs must pass the tests set out in subsection 38.3 of Part III of the UN Manual of Tests and Criteria (UN 38.3) prior to transport.

Substandard LiBs (LiBs that do not pass the UN 38.3 tests) are a growing concern [1] [2], so this study aimed to test the compliance of LiBs to the current transportation regulations and UN 38.3 to see if substandard LiB are being transported and what those hazards could be.

OBJECTIVES

The primary objective of this study was to verify the presence of substandard LiBs in the transportation system and examine their severity when failing UN 38.3 testing.

The study also looks at how suppliers are transporting LiBs and if the packaging and labelling follows current regulations. The objective is to identify any commonalities between substandard LiBs that could improve detection of them prior to or during transportation.

A third objective is to conduct a teardown analysis on substandard batteries to understand what may have caused the failures.

METHODS

The batteries tested in this study were selected based on which batteries had the highest volume purchased by consumers from global online marketplaces. Power tool batteries and replaceable smartphone batteries were found to be sold in significant quantities across all researched marketplaces. LiBs from three (3) power tool models and one (1) smartphone model were chosen for the study.

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For each model, one (1) set of LiB from the original equipment manufacturer (OEM) and five (5) sets of replacement LiBs from third-party manufacturers were selected (a set is 25 identical single battery units). The third-party sets were chosen based on cost, reviews, advertised specifications, shipping method, and advertised certifications received. Sets were identified by the equipment model (A, B, C for the power tools and D for the smartphone) and a numerical value from 1-6, with OEM batteries being assigned the number 1 (A1, B1, C1, D1)

UN 38.3 testing was performed according to the UN Manual Tests and Criteria, 7th edition [3]. Testing includes eight different tests labelled T.1 to T.8. For the LiBs selected for the study, T.6 and T.8 tests are not required for "small rechargeable batteries". Tests T.1 to T.5 are completed sequentially on the same battery, while Test T.7 is conducted on a separate battery that did not go through previous testing. The Tests are:

- T.1 – Altitude Simulation
- T.2 – Thermal Test
- T.3 – Vibration
- T.4 – Shock
- T.5 – External Short Circuit
- T.7 – Overcharge

For studying how the LiB packages were being shipped, an inspection checklist was developed with the assistance of Transport Canada Transportation of Dangerous Goods Inspectors. This checklist was used to document and photograph packages in a detailed and consistent manner, including instructions for requesting a UN 38.3 Test Summary and determining the LiB's state of charge (SOC).

RESULTS

As shown in Table 1, all OEM sets passed the required UN 38.3 tests. Ten of the twenty third-party LiB sets tested failed during UN 38.3 Testing. Non-compliances were found during T.3 – Vibration Testing, T.5 – Short Circuit Testing, and T.7 Overcharge Testing. Sets that failed T.5 and T.7 tended to result in fire and explosion events.

Table 1. Overview of UN 38.3 Test Results

Set ID	Result	Non-Compliances (NC)
A1	PASS	-
A2	FAIL	1 NC in T.3 Vibration 1 NC in T.5 Short Circuit
A3	FAIL	3 NC in T.3 Vibration
A4	FAIL	5 NC in T.5 Short Circuit 7 NC in T.7 Overcharge
A5	PASS	-
A6	FAIL	1 NC in T.3 Vibration
B1	PASS	-
B2	FAIL	4 NC in T.7 Overcharge
B3	PASS	-
B4	PASS	-
B5	PASS	-
B6	PASS	-
C1	PASS	-
C2	FAIL	1 NC in T.5 Short Circuit
C3	PASS	-
C4	FAIL	1 NC in T.3 Vibration
C5	FAIL	1 NC in T.3 Vibration 2 NC in T.7 Overcharge
C6	FAIL	7 NC in T.3 Vibration
D1	PASS	-
D2	PASS	-
D3	PASS	-
D4	PASS	-
D5	PASS	-
D6	FAIL	1 NC in T.3 Vibration

During fire and explosion failures of LiBs, it was typical to see a spike in voltage and a drop in current at the time of failure. Figure 1 shows batteries from B2 after the fire was extinguished and smoke was cleared, revealing the extent of the failure including the cells being charred or otherwise covered in debris.

Figure 1. Results of fire and explosion of a B2 battery during T.7 Overcharge Testing

A number of packages containing LiBs arrived with dents on the outer box. However, since undamaged packages resulted in failures and damaged packages resulted in passing results, package conditions at receipt does not appear to correlate to the UN 38.3 testing results.

While there is no expectation for a seller to provide a UN 38.3 Test Summary with each shipment, they need to provide it when requested [3]. In practice, it was difficult to contact sellers and for those that could be contacted they were either unable to provide one, did not know what it was, or provided a Test Summary that did not match the LiB received.

Lithium batteries that are shipped under shipping name UN3480, LITHIUM ION BATTERIES and transported by air mode are required to be at 30% state of charge (SOC) or lower. The lower SOC provides an additional layer of safety during transport and reduces the likelihood and severity of a thermal event. Only three sets could be confirmed to have been shipped by air: A4, B2, and C6. All three (3) sets had LiB that were tested to have a SOC above 30%.

Different packaging and labeling are required depending on the destination country, mode of transport, lithium content, and the total power of individual LiBs. In this study, the batteries were shipped to USA for testing, so the packaging and labelling requirements in the USA (49 CFR 173.185) were used to determine compliance [4]. 16 of 24 sets had packages without the correct markings, labelling, and/or packaging requirements, and these non-compliances were seen in both OEM and third-party batteries. 10 of the 24 sets had packages that were completely undeclared. A summary of all non-compliances is in Table 2.

Table 2. Results Summary of Non-Compliances

Set ID	UN38.3 Test	Package / Label	State of Charge
A1	PASS	PASS	N/A
A2	FAIL	FAIL	N/A
A3	FAIL	PASS	N/A
A4	FAIL	FAIL	FAIL
A5	PASS	PASS	N/A
A6	FAIL	FAIL	N/A
B1	PASS	FAIL	N/A
B2	FAIL	FAIL	FAIL
B3	PASS	PASS	N/A
B4	PASS	FAIL	N/A
B5	PASS	PASS	N/A
B6	PASS	FAIL	N/A
C1	PASS	PASS	N/A
C2	FAIL	PASS	N/A
C3	PASS	FAIL	N/A
C4	FAIL	FAIL	N/A
C5	FAIL	FAIL	N/A
C6	FAIL	FAIL	FAIL
D1	PASS	FAIL	N/A
D2	PASS	PASS	N/A
D3	PASS	FAIL	N/A

Set ID	UN38.3 Test	Package / Label	State of Charge
D4	PASS	FAIL	N/A
D5	PASS	FAIL	N/A
D6	FAIL	FAIL	N/A

In the teardown analysis, battery examinations and individual cell examinations were performed on the OEM batteries as well as their equivalent substandard batteries (for A and B sets only).

In terms of overall construction, only small differences were observed between the LiBs whether they passed or failed UN 38.3. The A1 OEM battery did exhibit additional safety features, but as these features were not present in the B1 OEM it isn't known if they would make a battery more likely to pass UN 38.3. The A4 battery had welds that looked like it was done manually with significant quality and spacing variance in each weld, but again it isn't known if they would make a battery more or less likely to pass UN 38.3.

The micro computed tomography (Micro CT) scan revealed sets A4 and B2 had notable defects that could lead to significant safety hazards, such as the fires and explosions seen during their UN 38.3 testing. These defects included cells with significant misaligned electrodes [Figure 2]. Misalignment can lead to dendrite formation on the electrodes, which can cause short circuits and thermal runaway conditions. Misalignments can occur during manufacturing or post-manufacturing abuse. No other cells had obvious defects that could lead to safety hazards. However, it is not possible to conclusively determine the root cause for each of the batteries that failed UN 38.3 tests since the teardown analysis was done on new batteries from the same set, but not on the failed battery itself.

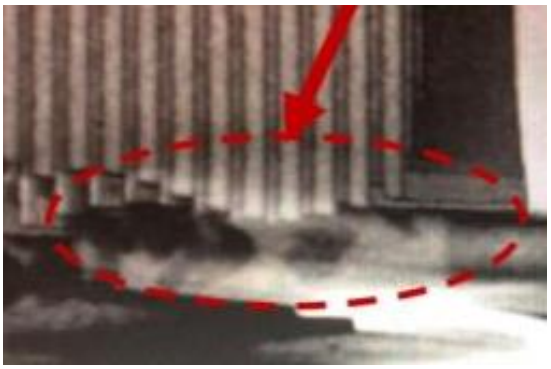

Figure 2. Misaligned electrodes in A4 cell

CONCLUSIONS

This study reveals that third-party (non-OEM) replacement batteries are more likely to be non-compliant with UN 38.3 tests, and thus can present a higher safety risk during transportation than their OEM counterparts.

UN 38.3 Testing, additional package documentation, and analysis conducted on 24 sets of batteries revealed that:

- All four (4) LiB sets from OEMs were compliant with UN 38.3
- Ten (10) of the twenty third-party sets had batteries that failed UN 38.3 (50%)
- All three (3) sets that were shipped by air contained LiBs that failed UN 38.3 and were shipped at a SOC greater than the 30% allowed
- Third-party LiBs with a high voltage (e.g., 20V) are more likely to be non-compliant with UN 38.3 tests than third-party LiBs with a lower voltage.
- It was difficult to get UN 38.3 Test Summaries from sellers
- More than half of the packages had incorrect labeling (third party and OEM), and 10 of the 24 sets had packages that were completely undeclared, including one OEM.
- UN 38.3 non-compliances occurred regardless of package weight,

handling, marketplace, shipper, courier, packaging & labeling compliance, and mode of transport
    - For sets that had severe failures during UN 38.3 tests (A4/B2/C2/C5), the substandard batteries were found to be cheaper and weighed less than their OEM counterparts, and had typos and/or misaligned texts on their labels.
- Teardown analysis revealed deficiencies in cells used in third-party batteries correlated with a higher probability of an incident than in OEM batteries

FUTURE ACTION

To help address the safety risks identified by this study, Transport Canada is developing strategies to increase awareness and compliance with safety requirements.

REFERENCES

[1] United States Department of Transportation - Pipeline and Hazardous Materials Safety Administration, "Safety Alert - Transportation of Hoverboards (Lithium Battery Powered Vehicles)"

[2] PRBA, "PRBA Urges Crackdown on Non-Compliant Lithium Ion Battery Manufacturers in China"

[3] UNECE, "UN Manual of Tests and Criteria Subsection 38.3, 7th Edition"

[4] Office of the Federal Register, "eCFR :: 49 CFR Part 173 -- Shippers -- General Requirements for Shipments and Packagings,.

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