

Evaluation and Analysis of Substandard Lithium Batteries by UN 38.3 Testing

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Thank You and Appreciation

- National Research Council Canada (NRC)
- Underwriters Laboratories (UL)
- United States Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA)

Background

- An increasing amount of replacement lithium batteries (LiB) are being ordered by consumers and being shipped in the transportation system including by air
- There is a concern that these third-party sellers may be producing substandard LiBs (LiBs that do not pass UN 38.3 testing), as well as not following shipping requirements for dangerous goods (packaging, documentation)
- Do substandard LiBs pose a greater risk to the air transport system over standard Original Equipment Manufacturer (OEM) LiBs? If so, what is the additional risk?

Study Objectives

1

Assess the presence of substandard LiBs in the transportation system, and their severity when failing UN 38.3 testing

2

Observe how suppliers conform to packaging and labelling requirements when transporting LiBs

3

Teardown analysis of substandard LiBs to determine possible cause of UN 38.3 failure.

*UN 38.3 testing is a requirement under the *Transportation of Dangerous Goods Regulations (TDGR)* for classification prior to transport. TDGR governs the transport of LiB shipments in Canada.

Scoping Exercise

From which markets are consumers purchasing LiBs?

- Top marketplaces in Canada
- Top marketplaces globally with an English storefront.
- Considered both physical stores with e-marketplaces as well as online-only stores

What LiBs are these markets shipping by volume?

- Sorting by best or most sold “lithium battery” products:

| |
|---------------------|
| 18650 Cells |
| Battery Pack LiB |
| Smartphone LiB |
| Power tool LiB |
| Laptop LiB |
| eBike LiB |
| Handheld vacuum LiB |

What would a consumer reasonably buy?

- Limiting products to easily replaceable, non-soldered batteries LiBs, smartphones and power tool batteries had the highest volume of sales across the selected marketplaces



**UN 38.3
Testing**

UN38.3 Test Matrix

16 Batteries tested per set

UN 38.3 Tests

T.1 Altitude Simulation

T.2 Thermal

T.3 Vibration

T.4 Shock

T.5 External Short
Circuit

T.6 Crush

T.7 Overcharge

T.8 Forced Discharge



Six (6) sets tested per model

One (1) set
from OEM



Five (5) sets
from third-parties



Four (4) models tested (Total of 24 Sets/384 Batteries)



Set A



Set B



Set C



Set D

Observing Supplier Protocols

Package weight differences

- From a previous TDG research project, different package configurations may change the handling conditions of LiB in shipping, which could play a factor in how it behaves in post-shipping UN 38.3 testing.
- Requested that batteries be purchased in two (2) separate orders: a small (<5kg) package and a large (≥ 5 kg) package.

Inspector Checklist

- A detailed checklist was developed with the help of TDG Inspectors across Canada to document the receipt of the packages:
 - Instructions for photographing outer and inner package as well as the batteries.
 - What are the package weight and dimensions?
 - Is the labelling of the outer package correct?
 - Is the shipping document correct?
 - Is there damage to outer or inner package?
 - Is there damage to the batteries?
 - Were UN 38.3 Test results provided?
 - Are other issues with the packaging?

Work

Contractor: UL (Underwriters Laboratory)

1. Procure 24 sets of replacement lithium batteries
 - Four (4) Top selling/ranking models from marketplaces
 - One (1) OEM set and five (5) third-party sets
2. Document the shipping papers, manifests, and packaging of batteries
 - Work completed in the United States so packages were compared to Title 49 of the U.S. Code of Federal Regulations (49 CFR)
3. Test them to the UN 38.3 Test Standard
 - But continue testing remaining batteries even when samples fail

Teardown Analysis

Contractor: NRC (National Research Council Canada)

- For batteries that failed UN 38.3 testing, fresh batteries from that same set went through teardown analysis to determine potential causes of failure at battery and cell-level.

Battery Pack Examinations

- General battery disassembly
- Cell placement
- Battery casing mechanical and thermal properties
- Inspection of connections and wiring

Cell Examinations

- Micro-Computed Tomography (micro-CT) Scan
- Dry room disassembly

Results – All UN 38.3 Test Results



| Set ID | T.1 | T.2 | T.3 | T.4 | T.5 | T.7 | Result |
|--------|-----|-----|-----|-----|-----|-----|--------|
| A1* | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | PASS |
| A2 | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ | FAIL |
| A3 | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | FAIL |
| A4 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | FAIL |
| A5 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | PASS |
| A6 | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | FAIL |



| | | | | | | | |
|-----|---|---|---|---|---|---|------|
| B1* | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | PASS |
| B2 | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | FAIL |
| B3 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | PASS |
| B4 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | PASS |
| B5 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | PASS |
| B6 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | PASS |

* = Original Equipment Manufacturer

2022-10-18



| Set ID | T.1 | T.2 | T.3 | T.4 | T.5 | T.7 | Result |
|--------|-----|-----|-----|-----|-----|-----|--------|
| C1* | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | PASS |
| C2 | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | FAIL |
| C3 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | PASS |
| C4 | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | FAIL |
| C5 | ✓ | ✓ | ✗ | ✓ | ✓ | ✗ | FAIL |
| C6 | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | FAIL |



| | | | | | | | |
|-----|---|---|---|---|---|---|------|
| D1* | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | PASS |
| D2 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | PASS |
| D3 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | PASS |
| D4 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | PASS |
| D5 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | PASS |
| D6 | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | FAIL |

Results – UN 38.3 Test Failures

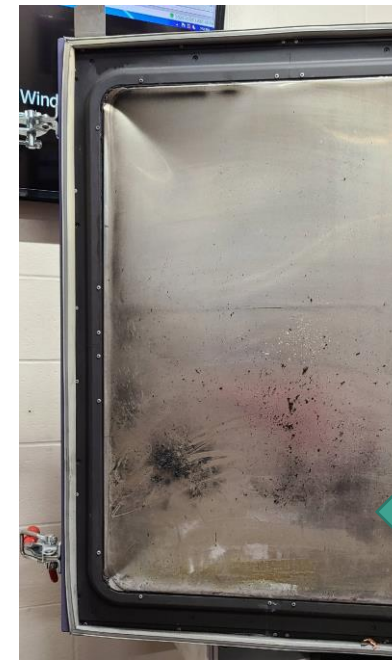
| Set ID | Notes |
|--------|--|
| A2 | One (1) lost voltage during vibration test (T3) One (1) exceeded max surf temp during short circuit test (T5) |
| A3 | Three (3) lost voltage during vibration test (T3) |
| A4 | Five (5) caught fire and exploded, created a dent in chamber door during short circuit test (T5) Seven (7) exploded during overcharge test (T7) |
| A6 | One (1) lost voltage during vibration test (T3) |



A4
Caught fire
and
exploded
during
overcharge
test



A4
Massive
explosion
during
short-
circuit test



A4
Explosion
caused
dent in the
chamber

Results – UN 38.3 Test Failures (cont.)

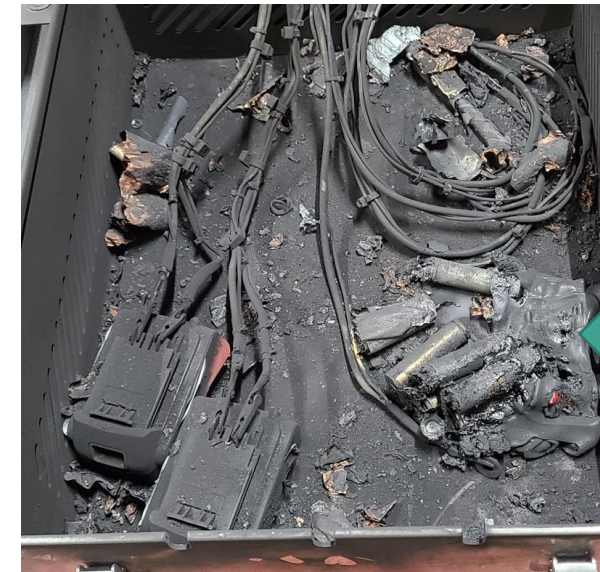
| Set ID | Notes |
|--------|---|
| B2 | Four (4) exploded during overcharge test (T7) |
| C2 | One (1) caught fire and exploded during short circuit test (T5) |
| C4 | One (1) lost voltage during vibration test (T3) |
| C5 | Two (2) lost voltage during vibration test (T3) One (1) caught fire and exploded during short circuit test (T7) |
| C6 | Seven (7) lost voltage during vibration test (T3) |
| D6 | One (1) lost weight and had a tear during vibration test (T3) |



B2



C2



C5

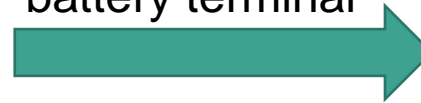


Results – Shipping Damage

| Set ID | Damage |
|--------|---|
| A1* | Outer Boxes Dented Blister Pack containing battery cracked, exposing battery |
| A5 | Box dented |
| A6 | Box dented |
| B6 | Boxes dented Damage to terminals on one battery |
| C1* | Boxes dented |
| C2 | Boxes dented |
| C3 | Boxes dented |
| C4 | Boxes dented |
| C5 | Boxes dented |

* = Original Equipment Manufacturer (OEM)

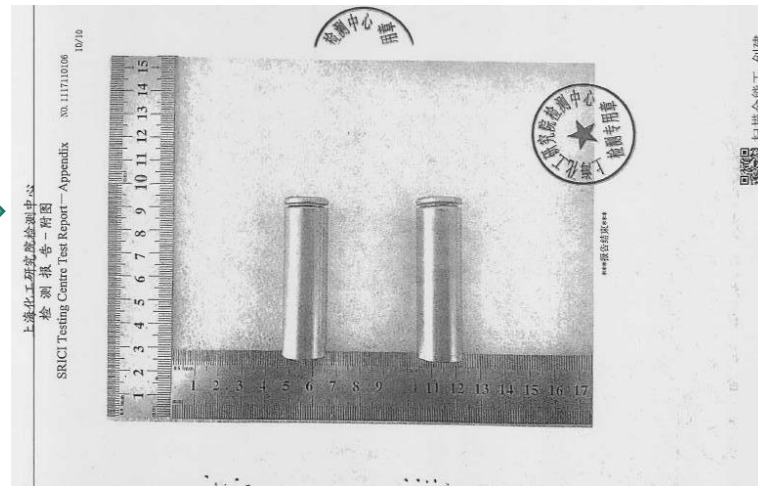
Outer/Inner
Packaging leading
to damage to
battery terminal



Results – UN Test Summary Requests

- When placing each order, an attempt was made to request the Test Summary for that battery design. A second attempt was made after receiving the packages and finding the seller did not provide any UN 38.3 test summary.
- In general, it is very difficult to contact sellers, and many sellers that were contacted failed to respond or stated that they were unable to provide a test summary.
- Out of the four (4) sellers that provided Test Summaries, three (3) of them did not match the product.

Test Summary provided were
done on cells, not battery packs



Results – Labelling Non-Compliances

| Set ID | Non-Compliances |
|--------|--|
| A2 | No Class 9 Lithium Battery or UN3480 label No “forbidden for transport by aircraft and vessel” |
| A4 | No Class 9 Lithium Battery label Incorrect label (UN3481 label) Another package has no labels |
| A6 | No Lithium Battery Mark No “forbidden for transport by aircraft and vessel” |

A4 - Incorrect label



Results – Labelling Non-Compliances

| Set ID | Non-Compliances |
|--------|---|
| B1 | No Lithium Battery Mark No “forbidden for transport aboard passenger aircraft” |
| B2 | No Lithium Battery Mark No “forbidden for transport aboard passenger aircraft” Package >10 kg, but not shipped fully regulated |
| B4 | Incorrect Lithium Battery Mark Missing information (no phone number) No “forbidden for transport aboard passenger aircraft” or “Cargo Aircraft Only” |
| B6 | No Lithium Battery Mark No “forbidden for transport aboard passenger aircraft” OVERPACK does not appear on the outside of the overpack |



B4 - Missing phone number

Results – Labelling Non-Compliances

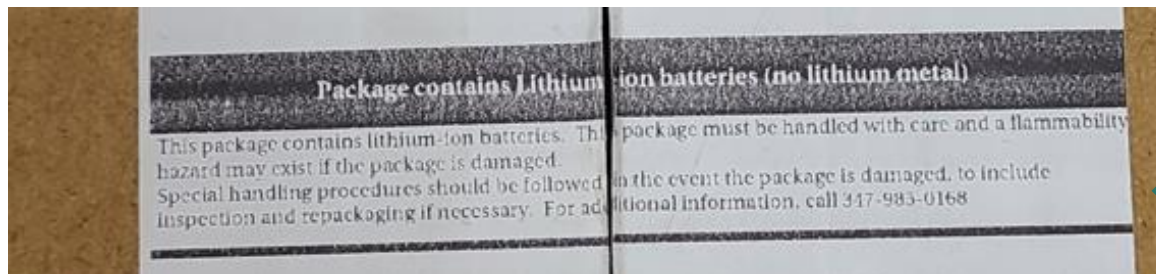
| Set ID | Non-Compliances |
|--------|--|
| C3 | No Lithium Battery Mark No “forbidden for transport aboard passenger aircraft” |
| C4 | No Lithium Battery Mark No “forbidden for transport by aircraft and vessel” |
| C5 | Battery label does not include UN3480 marking No “forbidden for transport aboard passenger aircraft” Uses older version of the lithium battery mark that is no longer authorized |
| C6 | Incorrect Lithium Battery Mark (UN3481) No Class 9 Lithium Battery label No Cargo Aircraft Only label |

C4 - Missing all markings



Results – Labelling Non-Compliances

| Set ID | Non-Compliances |
|--------|--|
| D1 | No “forbidden for transport aboard passenger aircraft” |
| D3 | No USPS Handling Label No text marking Surface Mail Only Outer package not appropriate |
| D4 | No Lithium Battery Mark No “forbidden for transport aboard passenger aircraft” |
| D5 | No Lithium Battery Mark No “forbidden for transport aboard passenger aircraft” Outdated markings that is no longer authorized |
| D6 | No Lithium Battery Mark No “forbidden for transport aboard passenger aircraft” Outdated markings that is no longer authorized |



Outdated marking

Results – State of Charge Compliance

- Lithium batteries that are shipped under UN3480 and transported by air are required to be at 30% State of Charge (SOC) or lower
- Only three (3) out of 24 sets can be confidently assumed to be shipped by air, and all three (3) sets had batteries arriving with an SOC over 30%.

| Set ID | Number of LiBs with a SOC over 30% |
|--------|------------------------------------|
| A4 | 14 out of 16 tested (1% - 45%) |
| B2 | 8 out of 8 tested (63% - 64%) |
| C6 | 16 out of 16 tested (37% - 38%) |

Results Summary of Non-Compliances



| Set ID | Packing/Labelling | SOC | UN 38.3 |
|--------|-------------------|-----|---------|
| A1* | ✓ | - | ✓ |
| A2 | ✓ | - | X |
| A3 | ✓ | - | X |
| A4 | X | X | X |
| A5 | ✓ | - | ✓ |
| A6 | ✓ | - | X |



| | | | |
|-----|---|---|---|
| B1* | X | - | ✓ |
| B2 | X | X | X |
| B3 | ✓ | - | ✓ |
| B4 | X | - | ✓ |
| B5 | ✓ | - | ✓ |
| B6 | X | - | ✓ |

* = Original Equipment Manufacturer

2022-10-18



| Set ID | Packing/Labelling | SOC | UN 38.3 |
|--------|-------------------|-----|---------|
| C1* | ✓ | - | ✓ |
| C2 | ✓ | - | X |
| C3 | X | - | ✓ |
| C4 | X | - | X |
| C5 | X | - | X |
| C6 | X | X | X |



| | | | |
|-----|---|---|---|
| D1* | X | - | ✓ |
| D2 | ✓ | - | ✓ |
| D3 | X | - | ✓ |
| D4 | X | - | ✓ |
| D5 | X | - | ✓ |
| D6 | X | - | X |

Trends in UN 38.3 Non-Compliances

- All OEM battery packs (A1, B1, C1, D1) were compliant w/UN 38.3
- 10 out of 20 (50%) of the third-party sets recorded non-compliances
- UN 38.3 test failures occurred regardless of the marketplace /shipper/courier transporting the LiB and the package weight or handling conditions
- UN 38.3 Test failures occurred regardless of the compliance to packaging & labelling
- While UN 38.3 test failures occurred for LiBs shipped by both air and ground, all three (3) packages that were shipped by air contained LiBs that failed UN 38.3 (100%)
- Based on the limited data collected in this study, a third-party LiB with a high voltage has a higher chance of having a non-compliance than a third-party LiB with a lower voltage. Capacity does not seem to have as significant of an impact.

Severe UN 38.3 Non-Compliances

Severe non-compliances are test failures that resulted in fire or/and explosion events (A4, B2, C2, C5).

Characteristics common to these sets:

- Batteries were shipped with a SOC over 30%
- Batteries had a lower mass than the OEM batteries
- Non-compliances with packaging/labelling requirements
- No markings on battery or markings had typos
- A4 and B2 were shipped by air

Teardown Analysis

Battery Pack Examinations

- Only small differences were observed between the batteries whether they pass or failed UN 38.3
- OEM battery exhibited additional safety features
- A4 had welds that were manually welded with significant variance

Cell Examinations

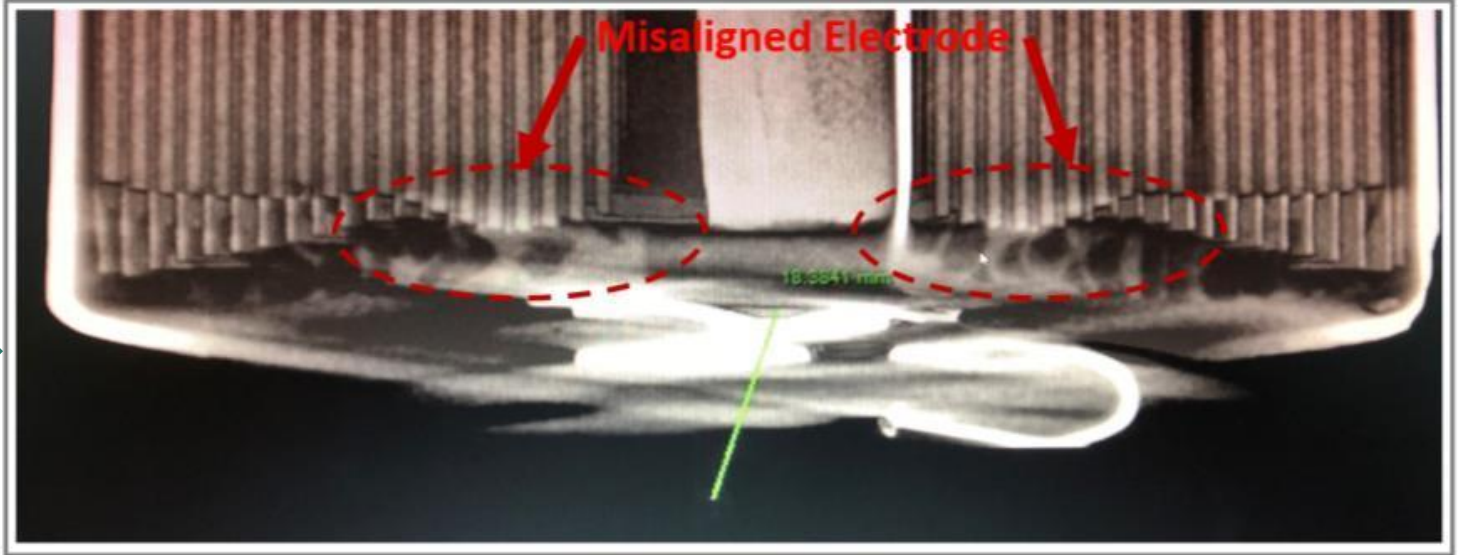
- Micro-CT Scan revealed significant misalignments
- Misalignment can lead to dendrite formation and eventually result in an exothermic runaway condition. Misalignments can be due to the manufacturing stage from a bad weld or post-manufacturing from abuse

None of these examination results necessarily correlate to fire/explosion events during the UN 38.3 tests

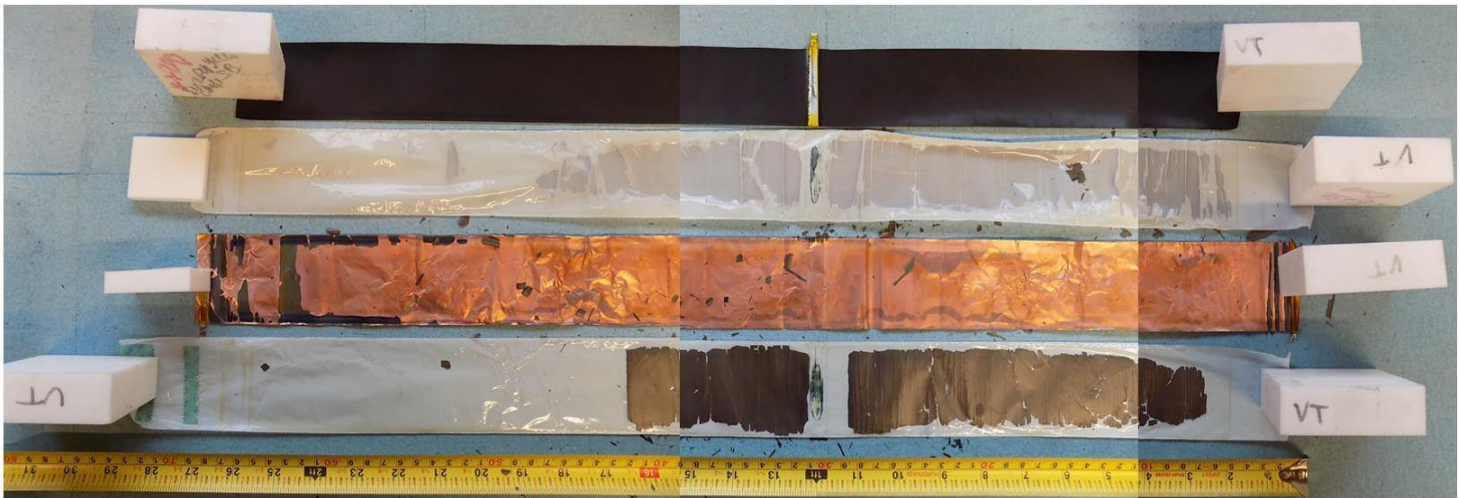
3

Teardown Analysis

Misaligned electrode in A4 cell



Disassembled A4 cell



Conclusions

Shipping/Labelling/Compliance

- Despite asking all suppliers for the UN 38.3 Test Summary of their battery design, most either did not know what it was or could not provide one
- More than half of the packages had no labels or had incorrect labeling
- State of charge measurements on all sets shipped by air were greater than the 30% maximum requirement

Testing

- All OEM battery packs (A1, B1, C1, D1) were compliant w/UN 38.3, while many of the third-party sets were non-compliant (50%)
- All three (3) packages that were shipped by air contained LiBs that failed UN 38.3
- Non-compliances occurred regardless of package weight, handling, marketplace, shipper, courier, packaging & labelling compliance, and mode of transport
- Teardown Analysis showed significant misalignments in cells within the battery sets that failed UN 38.3

Thank you – Questions?

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