BLACK DIAMOND STRUCTURES™

New MOLECULAR REBAR® Solutions To Address Corrosion/Adhesion-Based Failure

Enhancing the Corrosion Layer by Modifying the Active Mass Structure

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Vice-President, Research + Development

Who We Are

Black Diamond Structures™ is a global nanotechnology leader with the mission to help manufacturers create the next generation of world-class batteries.

Our unique products, based on proprietary **MOLECULAR REBAR®** technology, together with our team of world-class nanomaterial experts alter your battery's "DNA", unlocking its full potential… fast.

Our teams work directly with our customers to find solutions that enhance your battery's mechanical and electrochemical properties to meet market challenges for decades to come.

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YOUR NANO CONNECTION

Our Joint-Venture Partners

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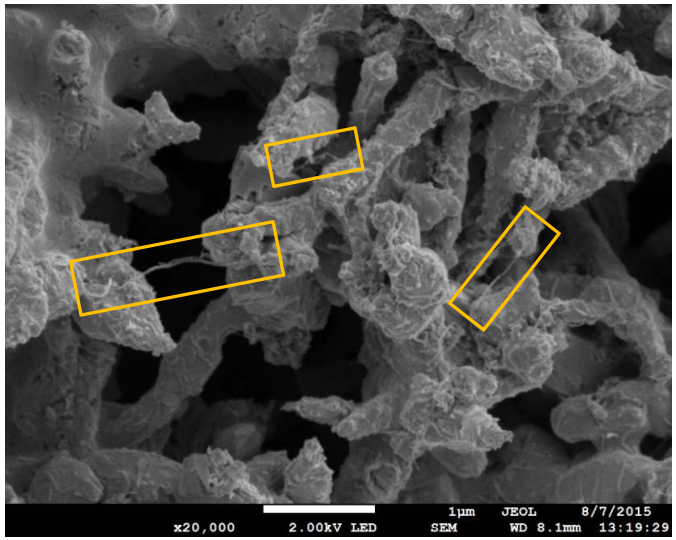
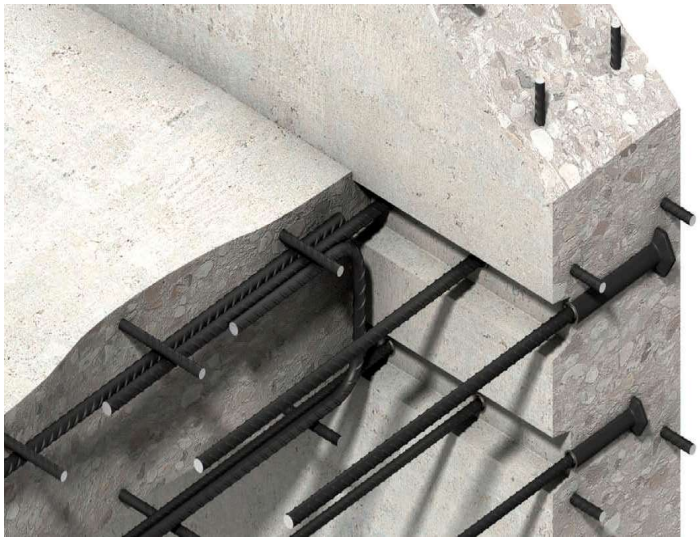
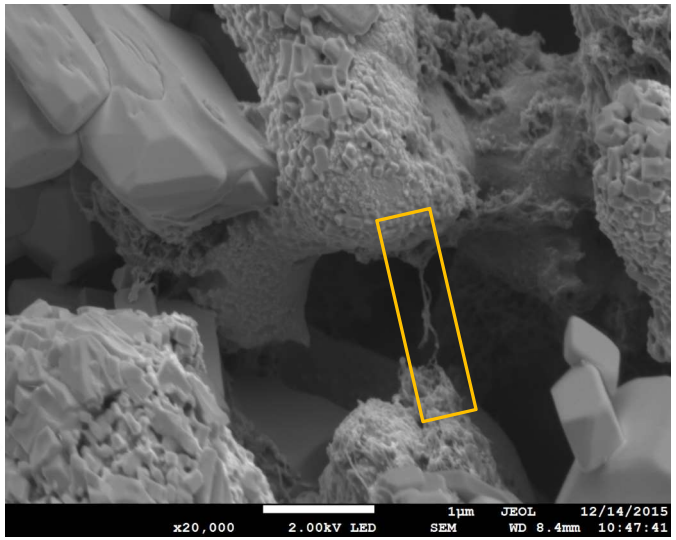
MOLECULAR REBAR® DESIGN

MOLECULAR REBAR®: The Nano-Connector

- **Molecular Rebar products provide nanoscale reinforcements which:**
  - Act to bring the active material together, reinforcing plate structure → **Enhanced robustness**
  - Alter crystal packing to enhance surface area and modify pore structure → **Improved electrical performance**
  - Restrict the growth of large, insulating lead sulfate crystals → **Consistency of performance**







Molecular Rebar Products Change the "DNA" of Your Battery

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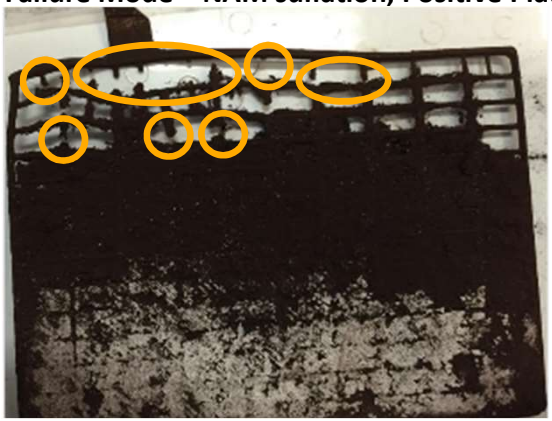
Molecular Rebar: Successful Against Corrosion

CONTROL

Failure Mode = NAM sulfation, Positive Plate Corrosion



Pb2300N + Pb2300P

Life Cycle Improvement = +150%

- **Previous Molecular Rebar PAM products:**
  - Commercially adopted mostly in Deep Cycle and AGM/VRLA applications
  - Some anti-corrosion properties are seen in Automotive and Flooded
- **BDS required better understanding to develop a targeted product:**
  - Tailored our DNA-changing technology to focus on corrosion mitigation
  - Explored our own mechanism of action, using it to drive product development
  - Performed joint-development work on formation and curing impacts
  - Targeted cost-to-value of any new solution

INTRODUCING PbAC SERIES OF PRODUCTS!

Corrosion: A Necessary Evil

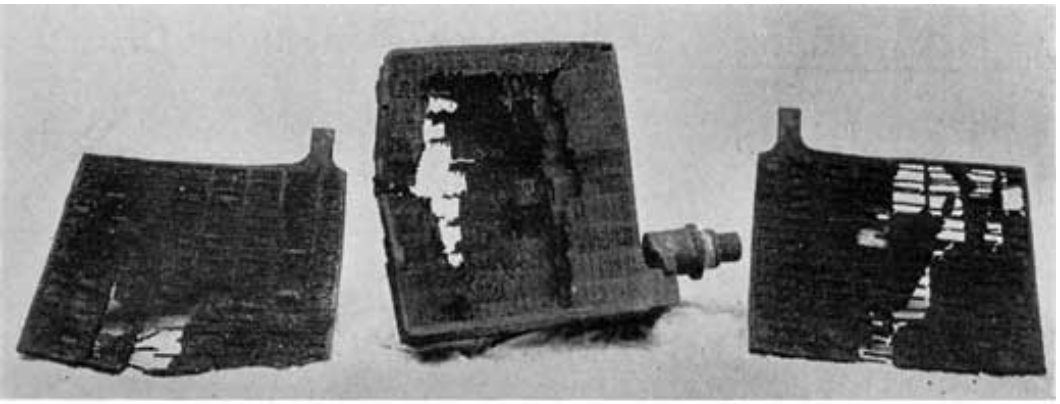


Fig. 210. Disintegrated Positives

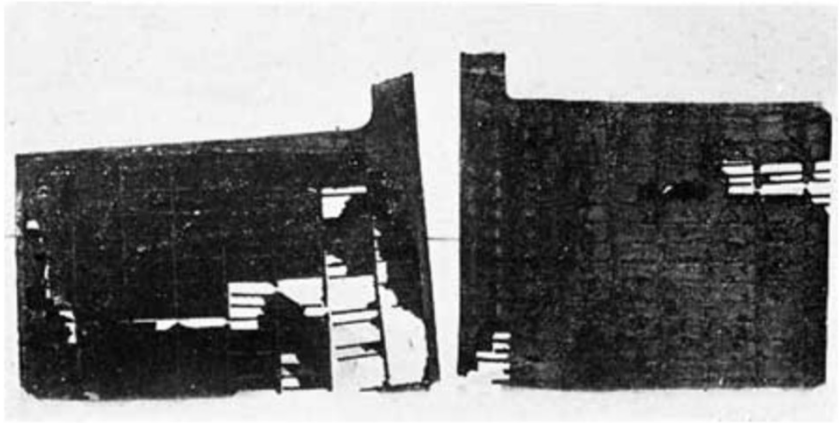
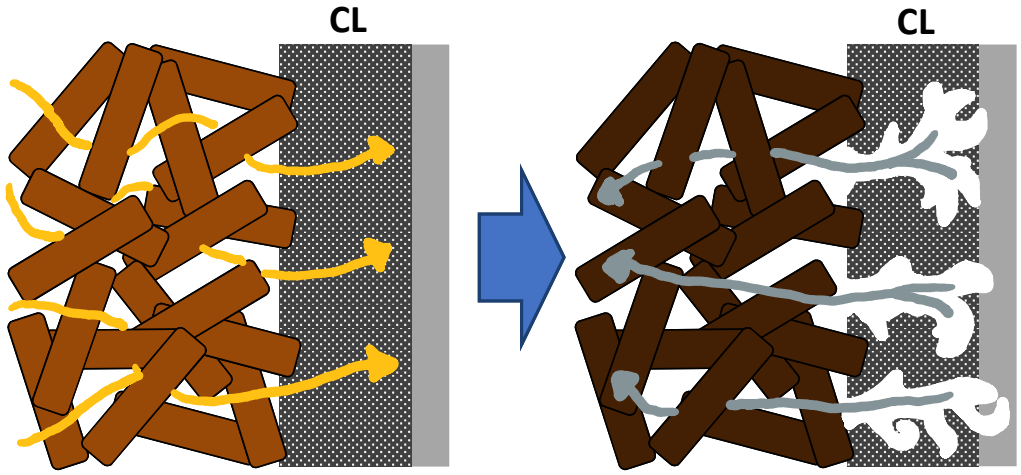


Fig. 206. Weak and Cracked Positives

- **Corrosion is unavoidable and fundamentally required for Lead-acid battery function**
- **Controlling it has always been a challenge**
  - ex. Ford “Model A” Manual from 1922
- **Made more difficult by higher operational temperatures in the engine compartment**
- **Increasingly difficult test standards intensify corrosion failure**

 A Witte. *The Automobile Storage Battery; Its Care and Repair*. **1922**

Mechanism of Corrosion

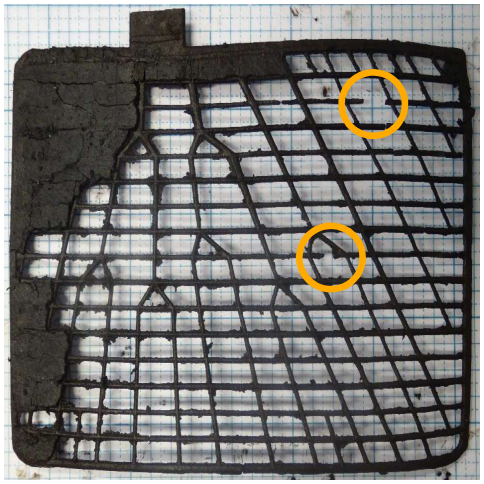


- Acid attacking the grid
- Corrosion Layer (CL) is built during curing/forming and is the 1st line of defense against further damage
- Defects and gradual wear of CL allow acid access to alloy
- Releases alloy components to PAM/NAM; weakens the grid and active mass
- Escaping metals aggravate gassing, ex. Sb poisoning
- Field Conditions that Exacerbate Corrosion:
  - Temperature
  - Over-charge
  - Over-voltage

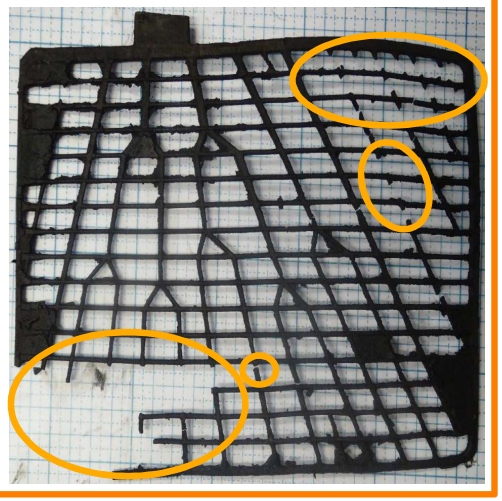
Advanced NAM Solutions Can Increase Corrosion

PAM Comparison Following 10 Weeks of KLT* (75 °C)

After Key Life Test, Plates are Dropped Once from 1m and Photographed



Low Carbon Sample
80% Active Material Lost
Few, Small Grid Breaks (O)



High Carbon Sample
95% Active Material Lost
Intensified Grid Breaks (O)

*IEC/EN proposed "Key Life Test" or KLT

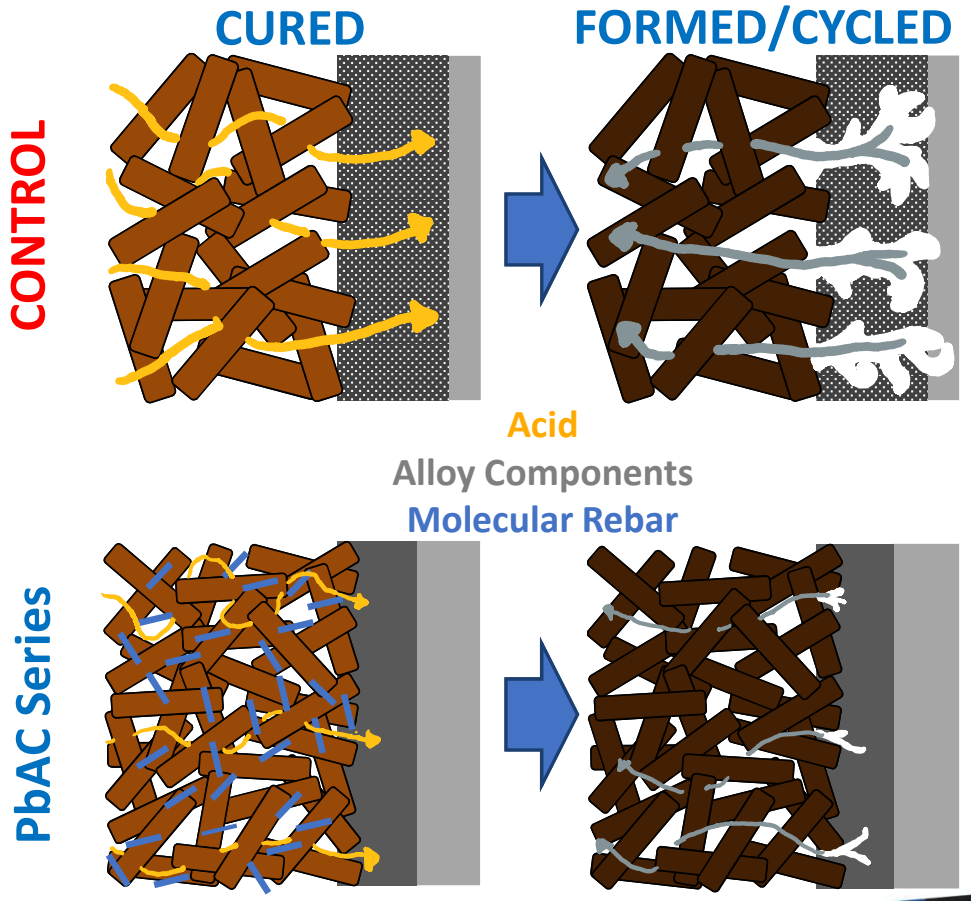
- **Industry has been Negative Plate-focused**
  - Charge Acceptance has been a dominant market driver for the last 10 years due to Start-Stop technology
  - Industry research concentrated on NAM improvements since that electrode is typically charge limiting
- **NAM advancements increase the occurrence of PAM-related failures, primarily due to grid corrosion**
  - Seen heavily in current technical specifications
    - eg. SAE J2801, SAE J240, JIS 5301D LLE, others
  - H_2O loss-induced acid concentration speeds corrosion
  - High-temperature operation intensifies corrosion
  - Decreased NAM polarization in charging overworks PAM

Present Solutions to the Corrosion Challenge

- **Inside-Out approach (grid changes)**
  - Implementation of new grid manufacturing technology
  - Increased Tin (Sn) in alloy
  - Specialty alloys
- **Outside-In approach (paste changes)**
  - Increased $[H_2O]_{plate}$ during cure – sticky plates, increased cure time, optimization
  - High temperature or steam curing
  - Exotics compounds
- **Solution must be balanced to avoid Premature Capacity Losses (PCL), often due to Poor Grid-to-Mass Adhesion**
  - PCL 1 & 2 First identified in switch to Pb/Ca alloys
    - PCL (1) insulating material or poor adhesion between grid and active material
    - PCL (2) active material softening

Our Approach: Build An Improved Corrosion Barrier

- **New PbAC Products are designed to modify the Corrosion Layer to improve plate robustness**
- **PbAC technology changes cured PAM "DNA"**
  - Uniformly affects the active material
    - **KEY TO ENABLEMENT**
    - Discrete, uniformly distributed MR
- **During formation, PbAC is a sacrificial agent**
  - Initially, energy goes to $PbO/PbSO_4$ *and* MR oxidation
  - Tempers energy delivery to system
- **A lasting effect on Corrosion Layer after formation**
  - Thinner, denser, more uniform
  - Improved Grid-to-Mass Adhesion
  - Changes persists through life
  - Shield grid from acid to prolong life



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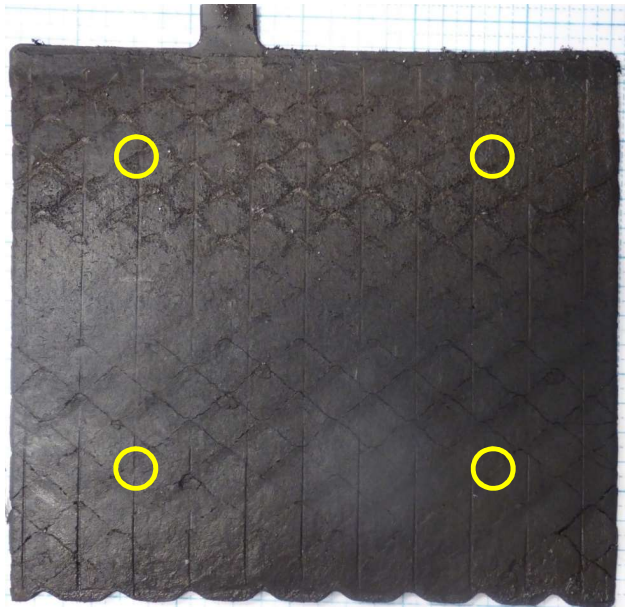
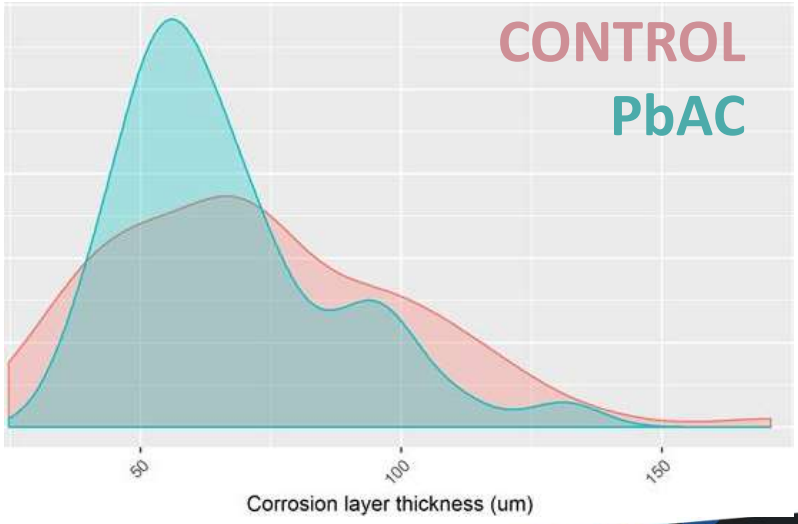
Corrosion Layer becomes More Uniform

- **Analysis shows a quantifiably thinner, more uniform corrosion layer with PbAC utilized in the positive plate**
- **Sampling technique selected to provide representative data**
  - Chose 4 plate locations for “whole-plate” analysis (yellow circles)
  - Grid samples are carefully excised to prevent active material loss and bathed in epoxy mounting liquid
  - Epoxy sections are cut, polished, sputter-coated with platinum, and imaged (JOEL)



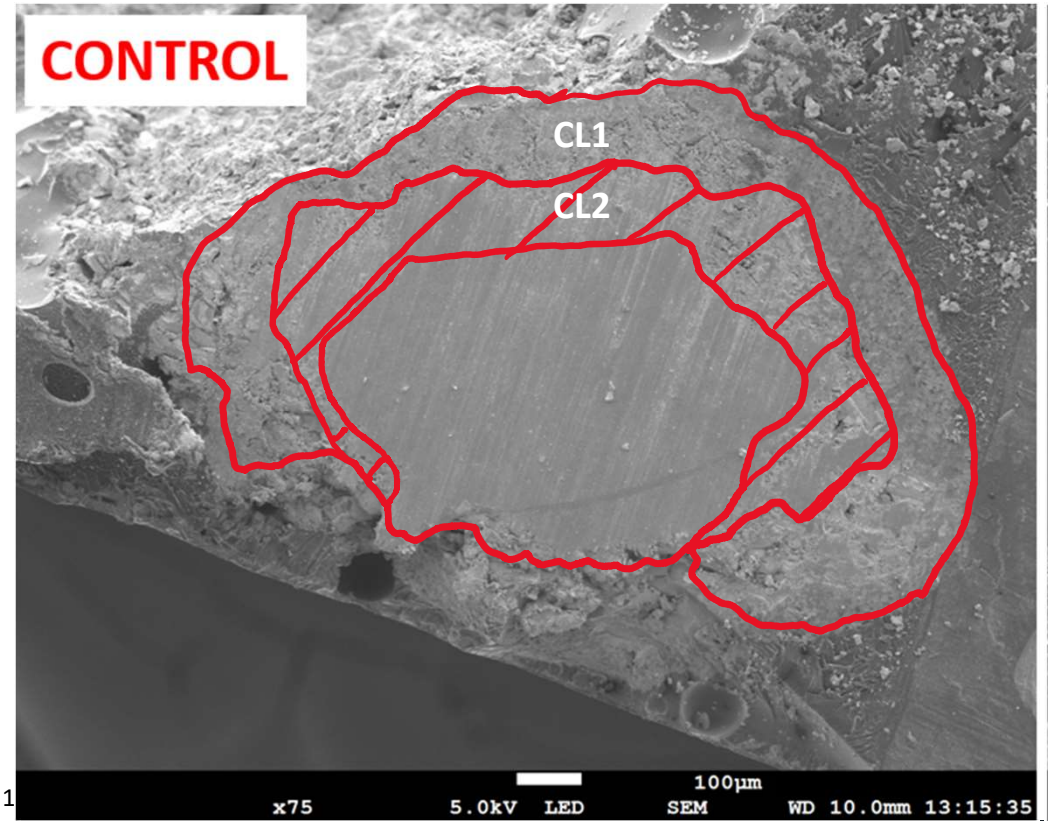
Sample Preparation
(Cut, Epoxy Mount, Polish)

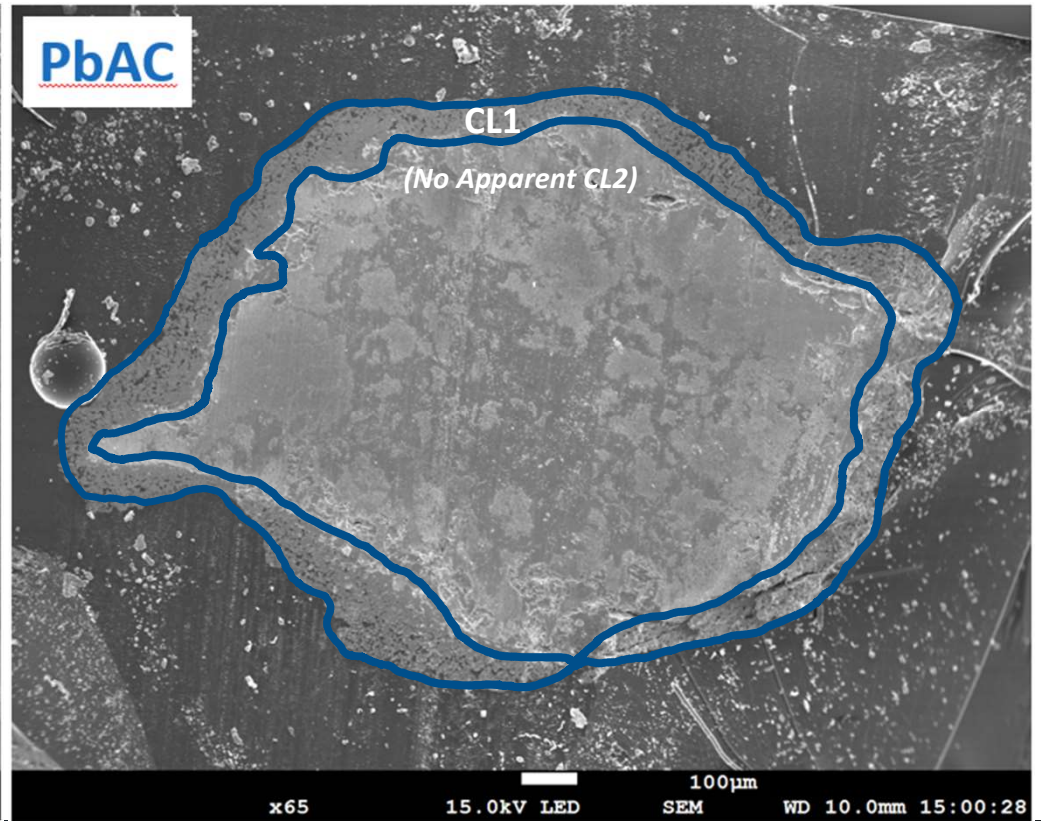
SEM Measurement



Enhanced Corrosion Layer Delays Corrosion-based Failure

- **PbAC generates a superior corrosion layer to improve cycle life >25% (SAE J2185 post life image below)**
  - PbAC layer is thinner, denser, more uniform, and as a monolayer instead of a bilayer
  - An effect of altered acid access, improved grid/mass adhesion, likely changed electrochemistry



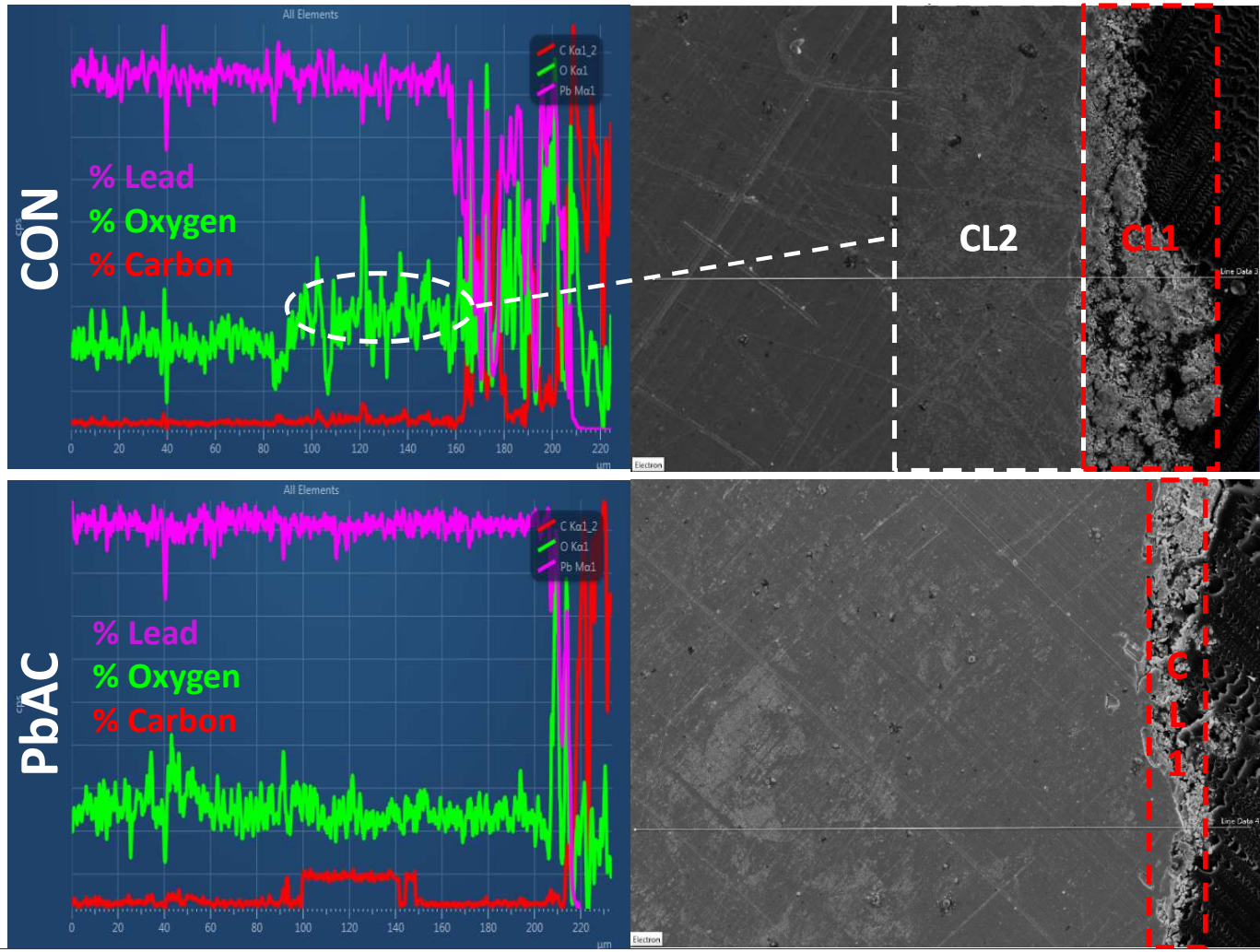


Enhanced Corrosion Layer Delays Corrosion-based Failure

- **PbAC enhancements are obvious even directly after Formation**

- **CON grid**
  - Shows 2 distinct corrosion layers
  - Thick, less uniform than PbAC
  - Less dense, “fluffier”
  - EDS shows corrosion layer as slowly increasing **O%**, slowly dropping **Pb%**

- **PbAC grid**
  - Shows 1 corrosion layer
  - Thin, more uniform than CON
  - More dense, tighter, more robust
  - EDS shows corrosion layer as quickly increasing **O%**, quickly dropping **Pb%**

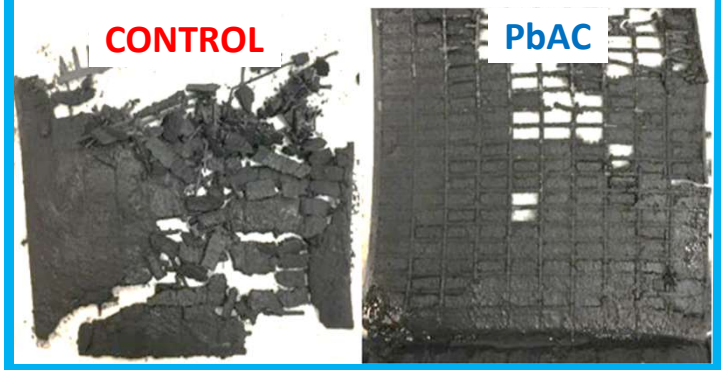


Dramatic Improvements Seen in Full-scale Testing

- **Implementation of PbAC results in an enhanced Corrosion Layer**
- **This new corrosion layer protects grid from further degradation and improves battery life where corrosion is the main failure**
- **Effects confirmed with:**
  - Grid Alloys
    - Ca/Sn, Ca, Sb
  - Grid Types
    - Cast, Expanded, Punched
  - ***…and counting!!***

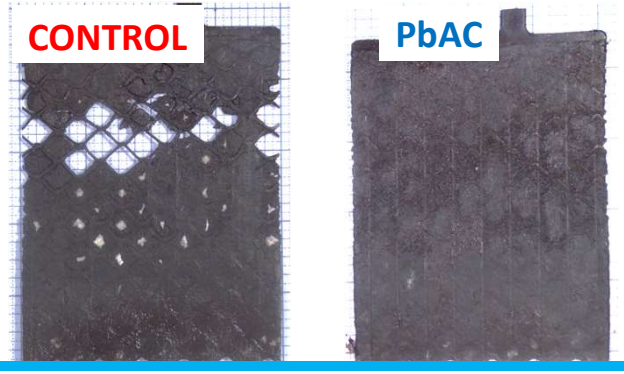
SAE J240 Cycling (75 °C) — Sb, Cast

60% improvement using PbAC to delay corrosion



JIS D5301 Cycling (41 °C) — Ca, Expanded

PbAC delays positive plate corrosion, material loss

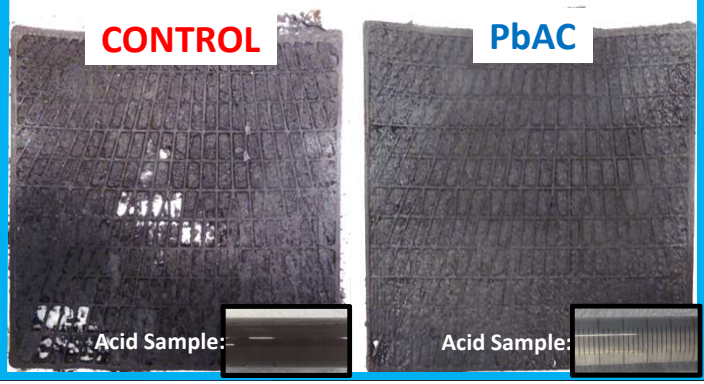


JIS D5302 Cycling (45 °C) — Ca/Sn, Cast

100% improvement using PbAC to delay corrosion

SAE J2185 Cycling (50 °C) — Sb, Cast

PbAC delayed corrosion and acid decolorization



Maximize PbAC Benefits By Working Together

Let Us Be Your Nano Connection!!

- **The Collaborative BDS Approach:**
  - ***Joint*** evaluation of needs and current challenges
  - ***Joint*** review of negative and positive grid/plate design
  - ***Joint*** analysis for formation procedures under use
  - BDS recommends PbAC product loading and other implementation considerations
  - BDS on-site to support trial
  - ***Joint*** analysis of formation data and confirmation of corrosion layer modification
  - Further validation in lab or field

- **Application Development Engineers stand ready in all geographies to assist you!!**
  - Leverages over 100 years of entrenched lead-acid battery experience
  - In constant communication with US-based R+D Team

Summary

- ***NEW PRODUCT RELEASE*: PbAC Series for Corrosion Resistance**
  - Improves the corrosion layer to protect the grid and enhance life in corrosion-limited applications
  - Easy adoption, no capital expense, application-development teams available to assist in implementation
  - BDS uses a collaborative approach and our Application Development Teams stand ready to support you

- **Cost reduction and/or performance improvements accessible with existing Molecular Rebar products:**
  - **Pb1100 Series** – Light and Heavy Duty SLI
  - **Pb1200 Series** – Enhanced Flooded Batteries
  - **Pb2x00 Series** – Deep Cycle (Flooded and VRLA)
  - *… and many more!!*

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