BLACK DIAMOND STRUCTURES™

MOLECULAR REBAR®:

Formulated Discrete Carbon Nanotube (dCNT) Additives

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BLACK DIAMOND STRUCTURES™

Who We Are

BLACK DIAMOND STRUCTURES™

Black Diamond Structures is a developer, manufacturer, and marketer of innovative nanomaterial products and solutions based on revolutionary discrete carbon nanotube (dCNT) technology, **MOLECULAR REBAR®**

Our Partners

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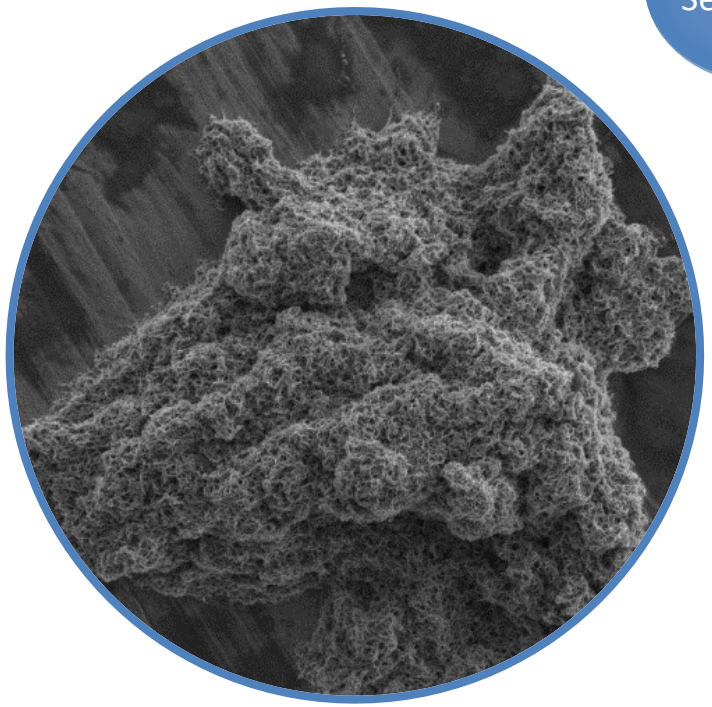
MOLECULAR REBAR® DESIGN

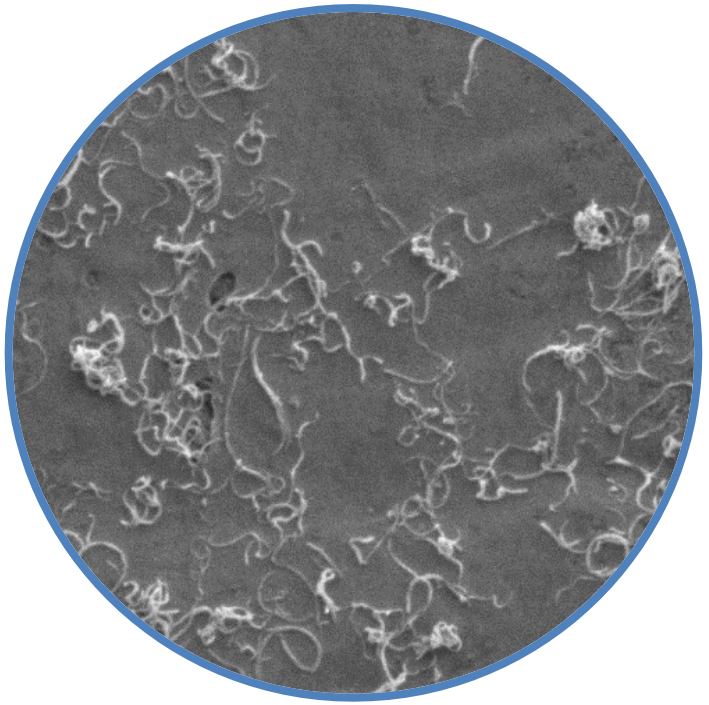
Detangling Traditional CNT into MOLECULAR REBAR

Key Technical Advantage

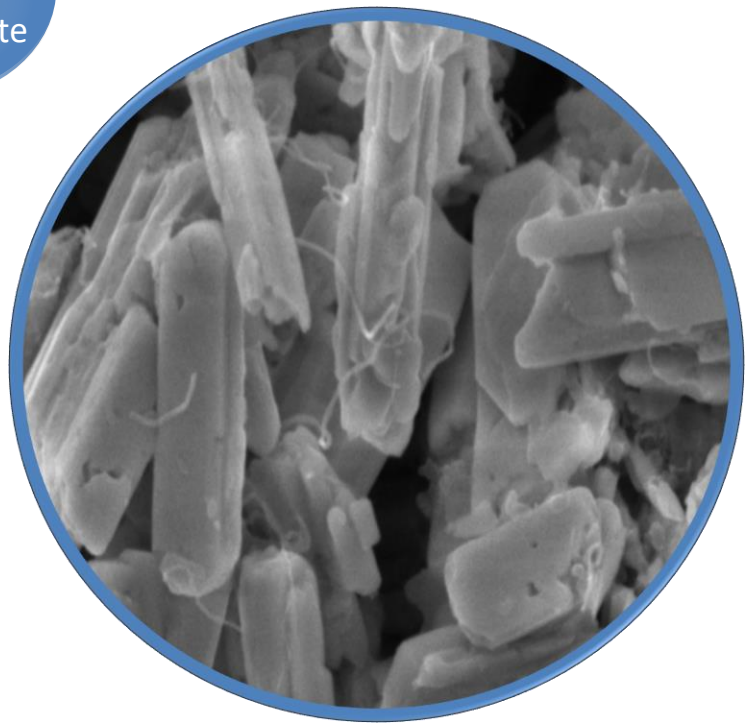
Bulk Carbon Nanotubes → Detangling/ Separation → Formulation - Dispersion → Master Batch - Concentrate → Customer Integration w/ End-Product



Clumps of Dirty, Entangled CNT's



Clean, Detangled MR *Discrete, Individual Tubes*



MR in Lead Paste
(or other substrates)

Formulation Key to Paste Incorporation, End Results

- For carbon compounds to be effective, they must fully integrate with the lead system; they must not simply be “along for the ride”

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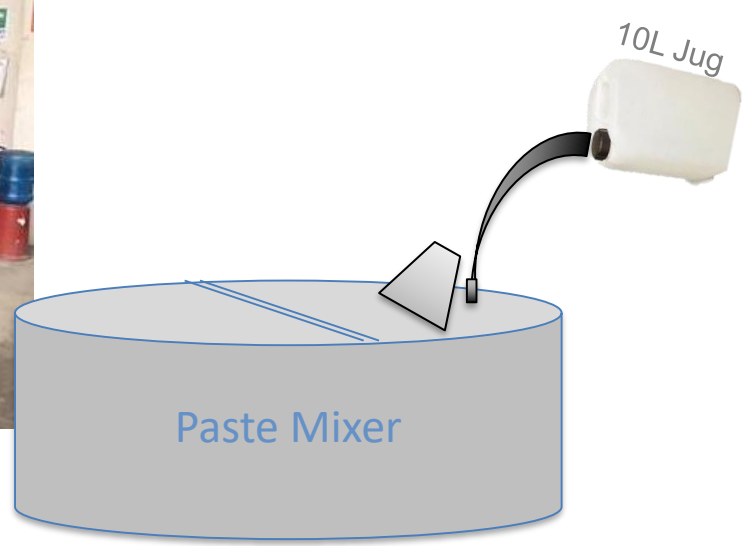
- **A volume of pasting water is replaced with the MOLECULAR REBAR® liquid, so total liquid volume remains fixed.**
  - No capital expenditures or modifications to pasting lines required.



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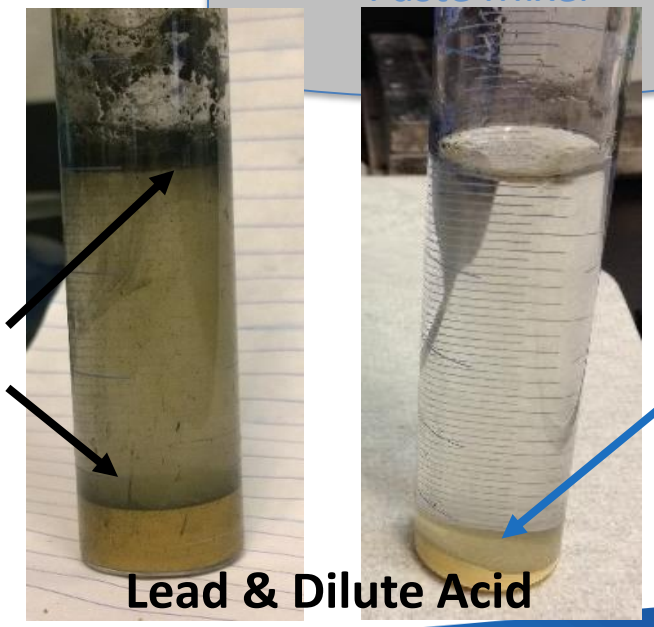
- Material is shipped as a pourable, aqueous liquid which incorporates beautifully with the lead system
- A volume of pasting water is replaced with the MOLECULAR REBAR® liquid, so total liquid volume remains fixed.
  - No capital expenditures or modifications to pasting lines required.
- **MOLECULAR REBAR® have specific affinity for lead oxide allowing them to integrate effectively**
  - Carbon poorly integrates into paste mixtures
  - Discrete CNTs associate with lead oxide and are easily cleared from aqueous mixtures



Carbon does not integrate with lead or acid

MOLECULAR REBAR® integrated into the lead

Lead & Dilute Acid

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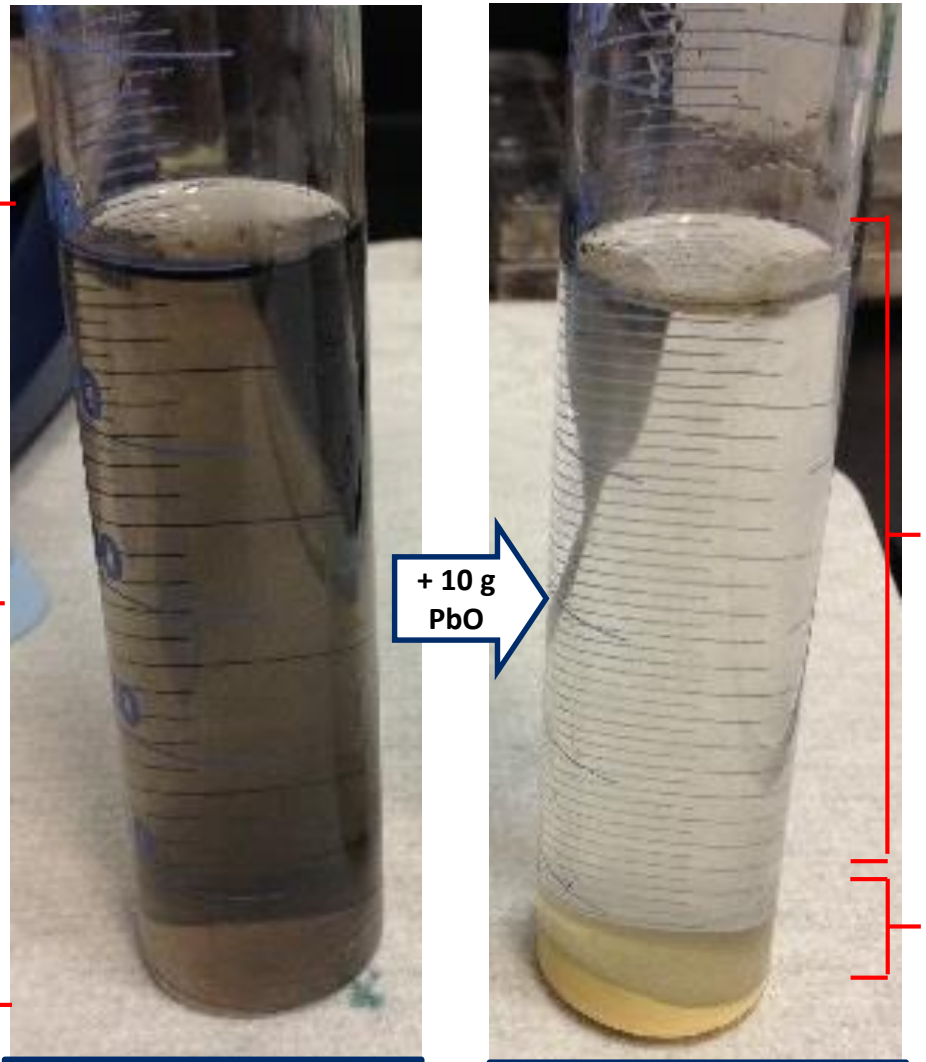
MOLECULAR REBAR® Integrate with PbO in H_2O/Acid

Molecular Rebar®



- MOLECULAR REBAR® uniformly mixes with water and acid in battery paste.
- MR is strongly attracted to the lead as automotive-grade lead oxide is added to mixtures of MR and water or acid
- MR has significant interaction with lead, water, and acid

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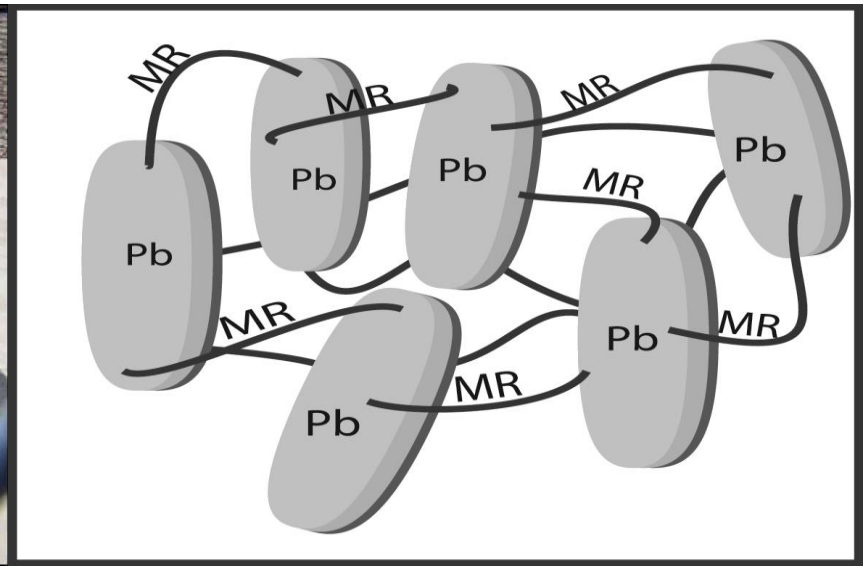
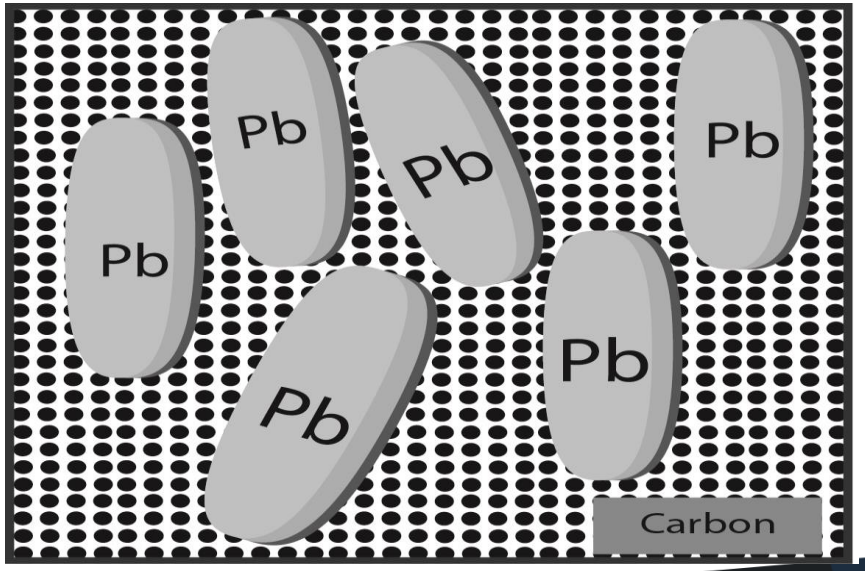
Not Another Carbon: Unique Form & Function



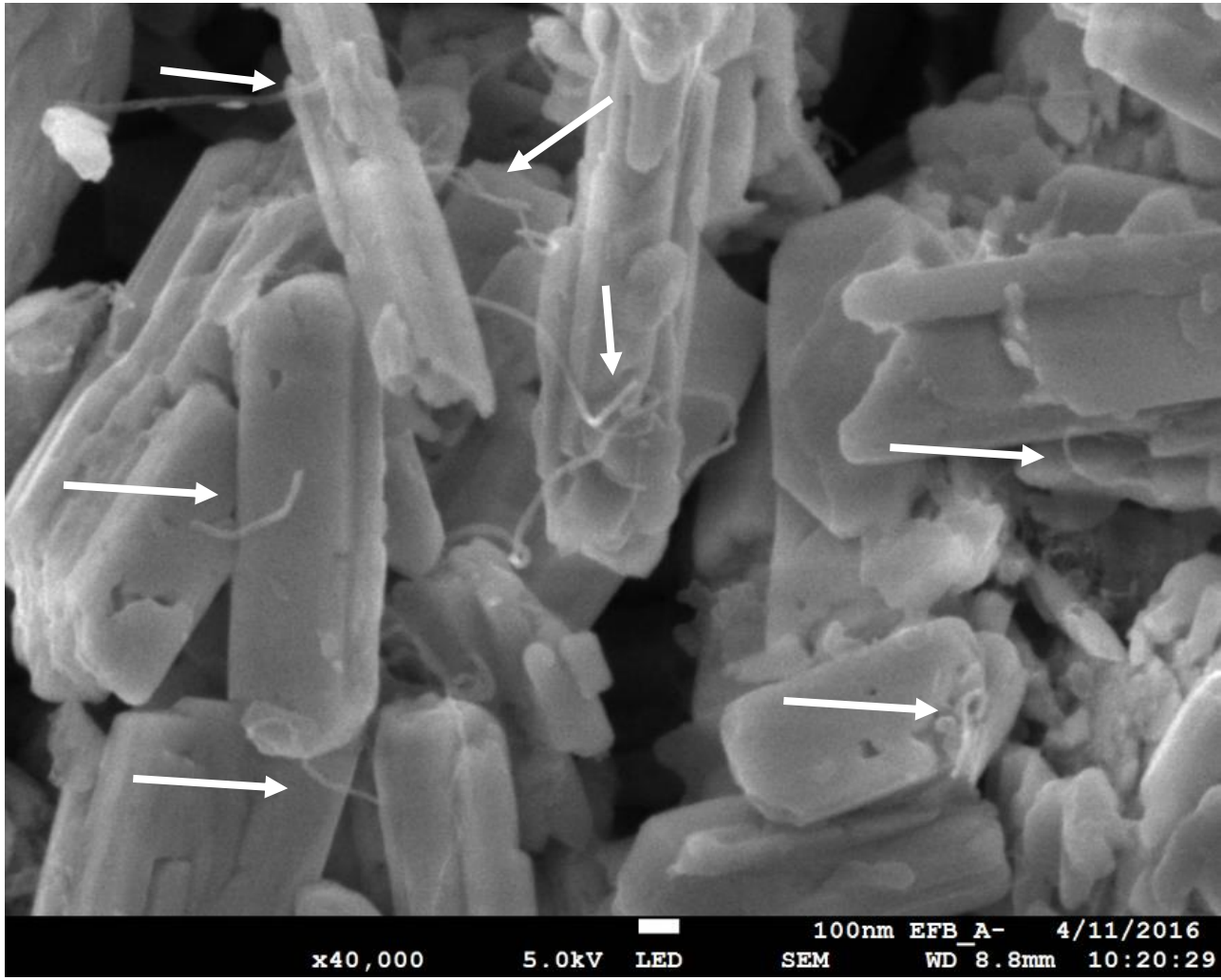
- MR acts a a physical and rheological modifying agent, its form and function are unique from Carbon; “Rebar Effect”
- Benefits of MR are no derived primarily from surface area, hence addition rates at 10% of less of Carbon



- Carbon has an important role in conductivity and is necessary in a lead acid battery
- Its interactions and purpose are different than MR

Not Another Carbon: Unique Form & Function

- **MR products are formulated for ease of use and incorporation**
  - No processing issues or the resulting performance issues (density, plate consistency, etc.)
  - Can be used alongside carbon, expander, other solutions with additional and even corrective benefits.
- **MR creates a network of individual nanotubes reinforcing the plates, adding lasting strength and durability**



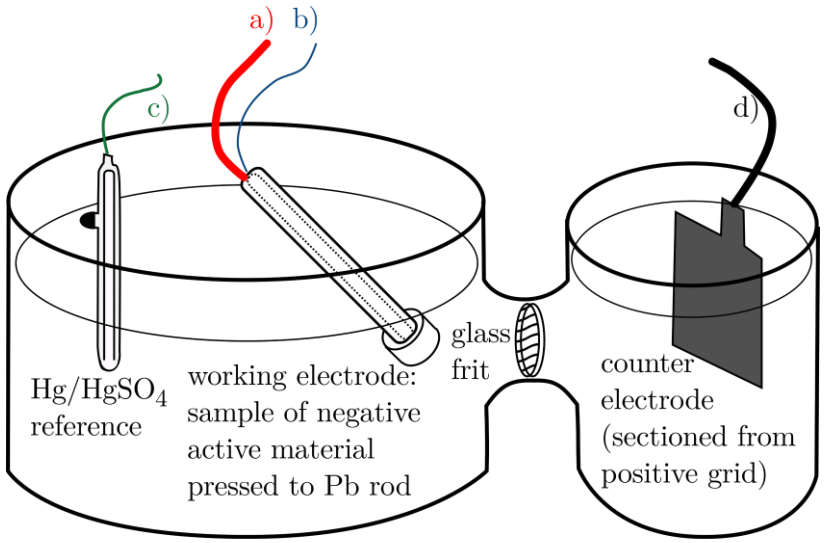
Consistent Benefits of MOLECULAR REBAR® Across Applications

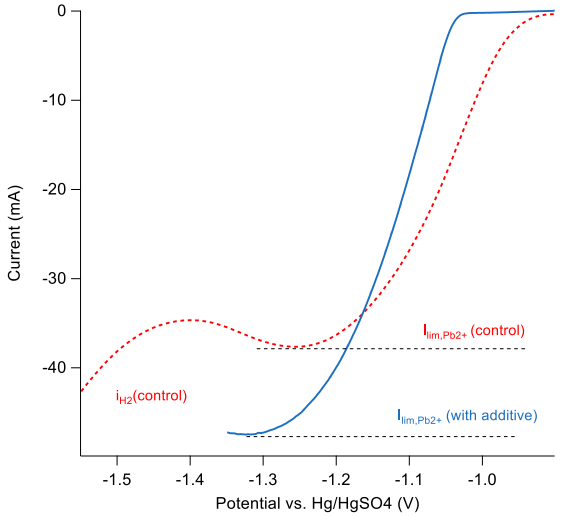
- **More Efficient Charging with dCNT**
  - Reduced Recharge Times
  - More Consistent Capacity & Charge Acceptance
  - *Allows Charging at Higher Rates without Transition to Gassing*

- **Improved Maintenance of the Micro-Structures**
  - Sustains a more Effective Conversion of Active Material
  - Reduces and Suppresses Irreversible Sulfation
  - *Observed both Chemical and Mechanical Improvement*

Finding Transition from Pb Charging to H_2 Evolution

- **Linear Sweep Voltammetry:**



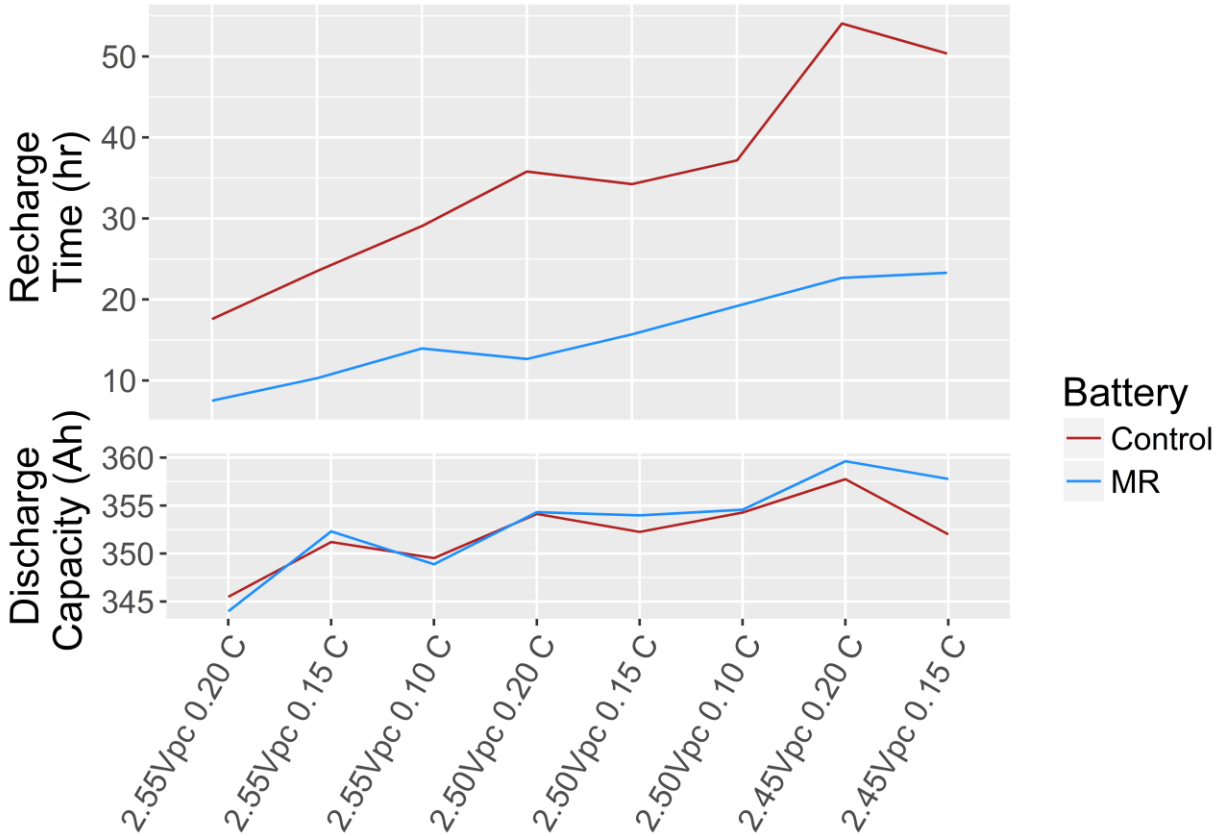


- **Pb charging can sustain higher limiting current with MOLECULAR REBAR® in NAM paste, either by promoting diffusion or attacking $PbSO_4$ particles.**

Recharge Time Reduction + Capacity Retention

Significant reductions in recharge time across numerous conditions/application charging conditions

Various V/i Charge Profiles to 115% after C-20 Discharges

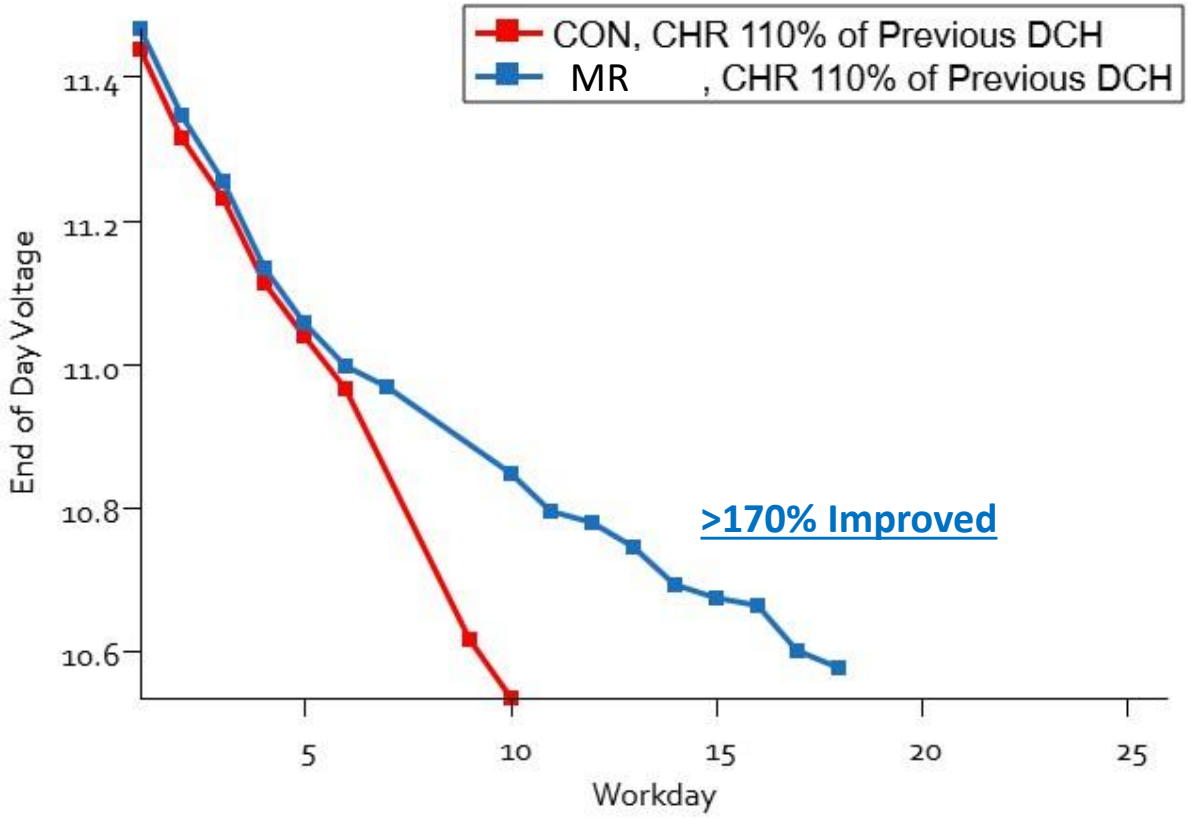


- MR has a major impact on charging from 90% SOC and beyond
- MR prolongs the Constant Current portion of charging
- MR increase the Current in the Constant Voltage portion of charging
- Even with much faster Ah return the conversion efficiency is high as shown by the maintained capacity.

Reduction in time versus Control to return 115% of the C20 Capacity of sets of 3ct 6V 500Ah Flooded batteries.

Improved Charge Efficiency

Lab Simulation Testing: Fixed Ah Input (110%)



The batteries are discharged for a "workday" using 10 cycles or "trips," each with five 10min discharges followed by a 10min rest, resulting in > 80% DOD over a 10-hour duration. Recharge is the same for all batteries and either 8-hours or 10-hours each workday. 12V 80Ah Flat Plate Batteries

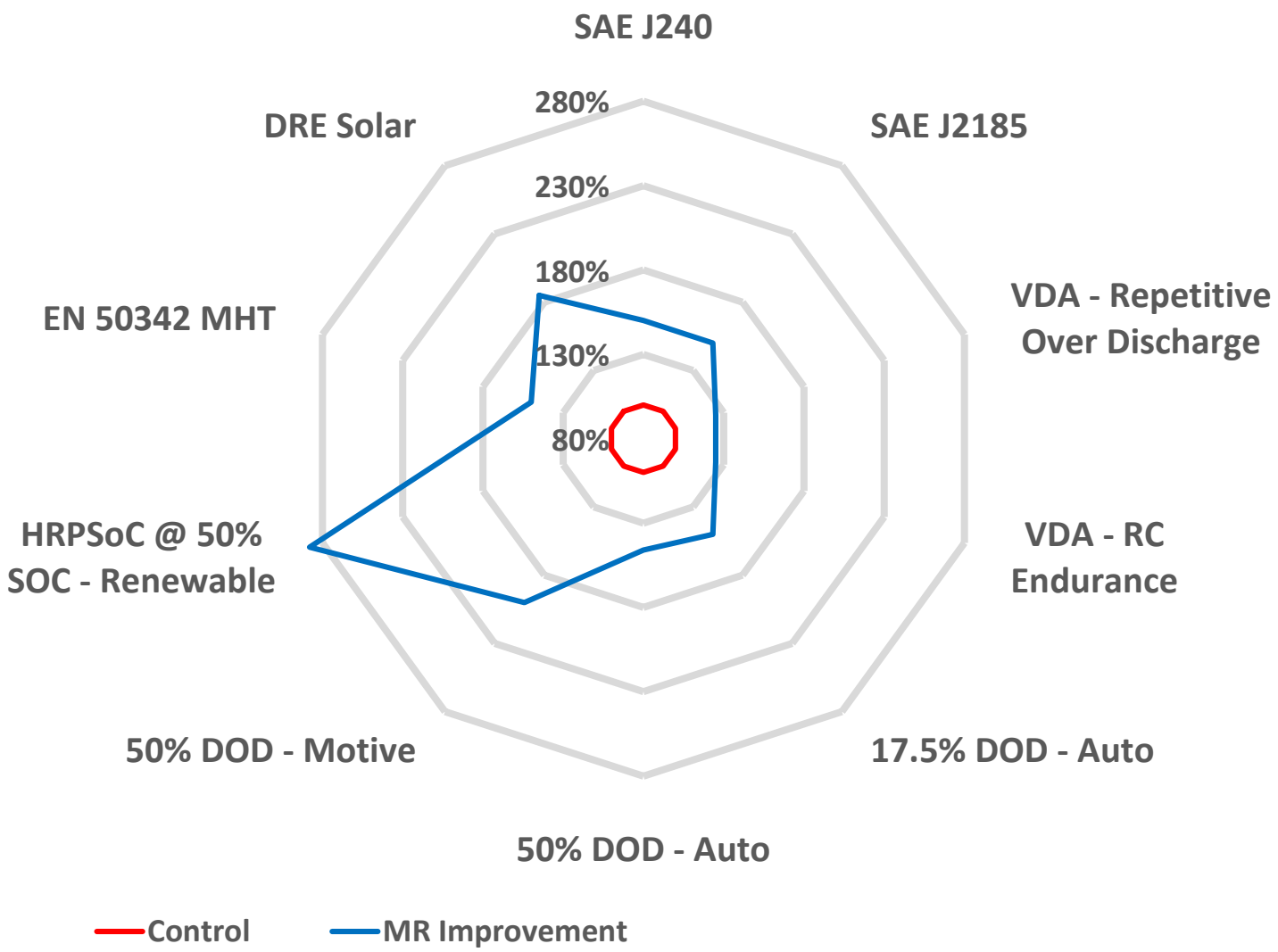
- All batteries charged to 110% of the Ah discharged during the workday cycle; 115% is recommended, simulation intentionally undercharged
- MR batteries converted more of the 110% Ah Input back into useable capacity and 70% more cycles
- MR Improves charge efficiency

More Efficient Charging with MOLECULAR REBAR®

- **More Efficient Charging with MOLECULAR REBAR®**
  - Reduced Recharge Times
  - More Consistent Capacity & Charge Acceptance
  - *Allows Charging at Higher Rates without Transition to Gassing*

Preserving Microstructure for Reliable Performance

Customer Provided Durability Focused Cycle Tests

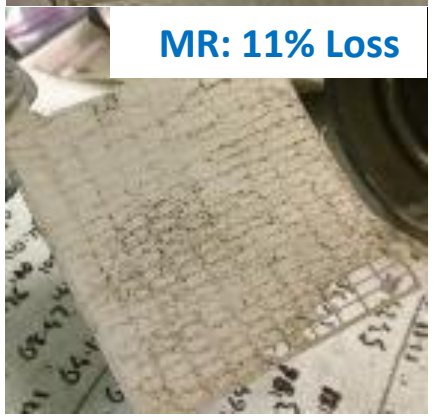


- MR strengthens and maintains the microstructure of the Negative and/or Positive Active Material
- The added Mechanical Integrity & Durability through MR addition can be seen through extended cycle life in many tests by reducing or preventing:
  - Active Material Shedding
  - Active Material Growth
  - Sulfation
  - Grid Corrosion

Increased Plate Durability

- MR the increase the strength of the active material, reinforcing the lead matrix
- Qualitative and Quantitative tests indicate increased strength of the micro-structure

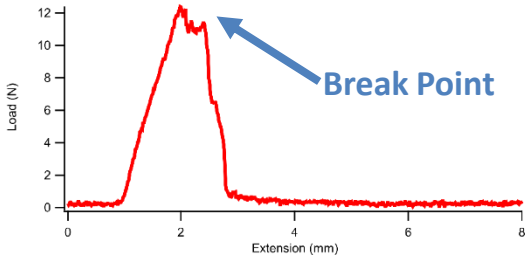
3 Impact Test



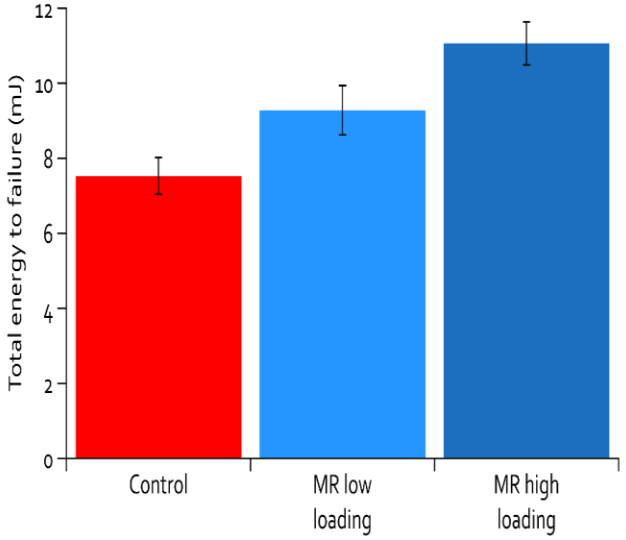
Quantitative Energy-to-Break Test

Instron Material Strength Analyzer

Plate Strength Measuring Adaptation



Force to Energy-to-Break Calculation



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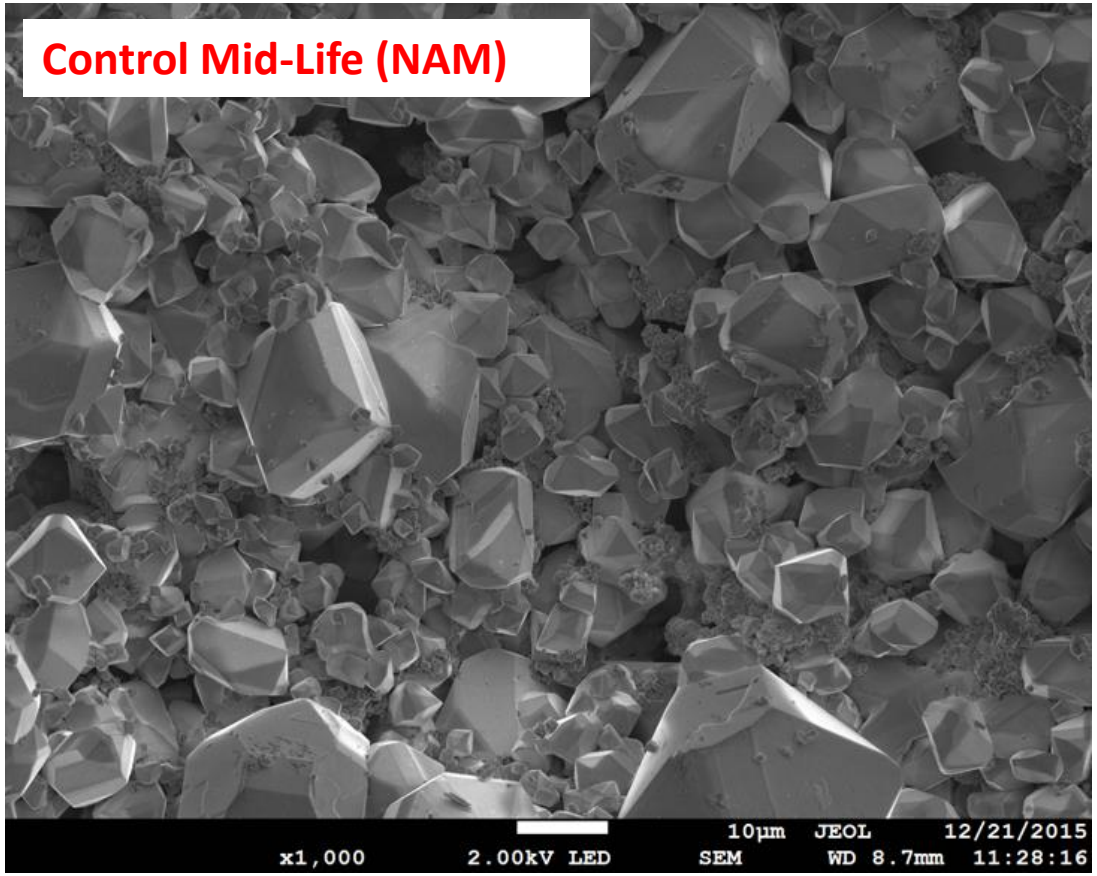
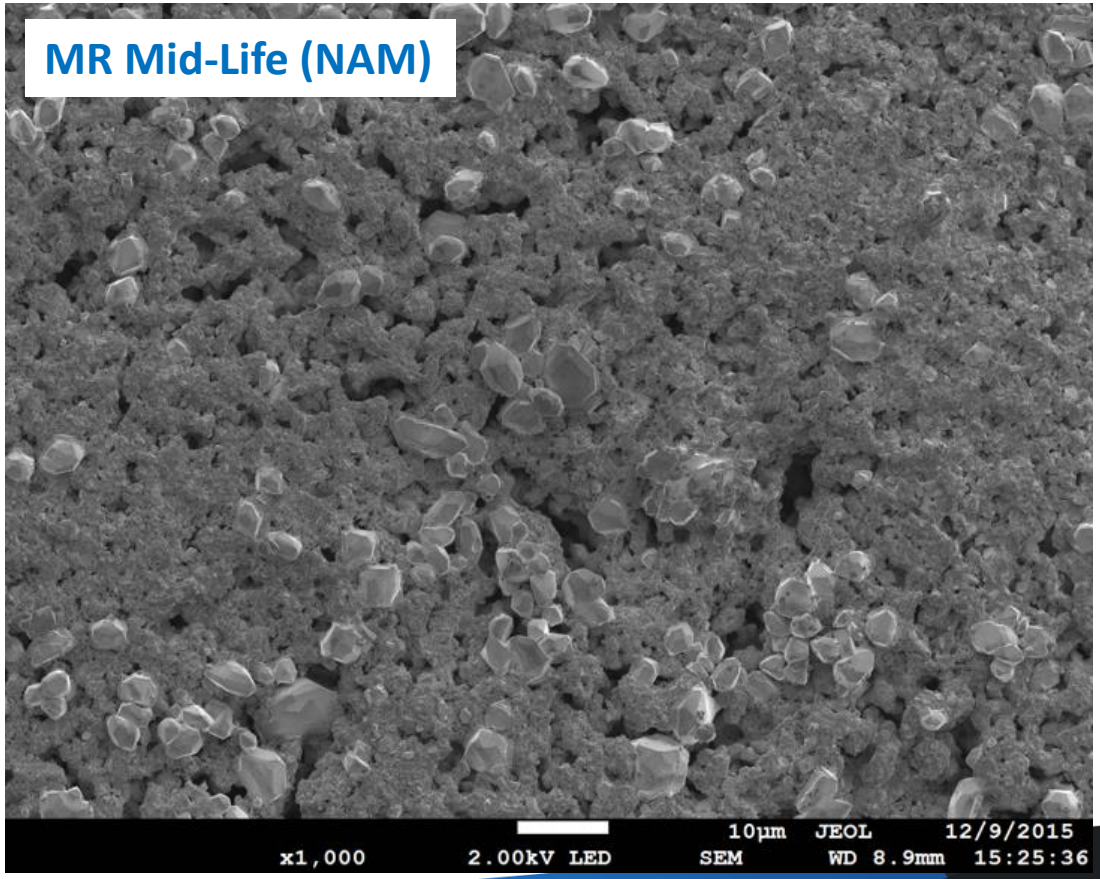
Retaining Microstructure in PSoC Cycling

- **After >4 Months of intensive PSOC cycling:**
  - MR decreases sulfate crystal size and frequency allowing the majority of the plate to remain as active sponge lead
  - Plates are noticeably stronger to the touch upon teardown; dCNT strength benefits retained through life



Micrographs at 1000x resolution illustrate MR's ability to ensure uniform NAM crystal structure even after > 4 months of cycling



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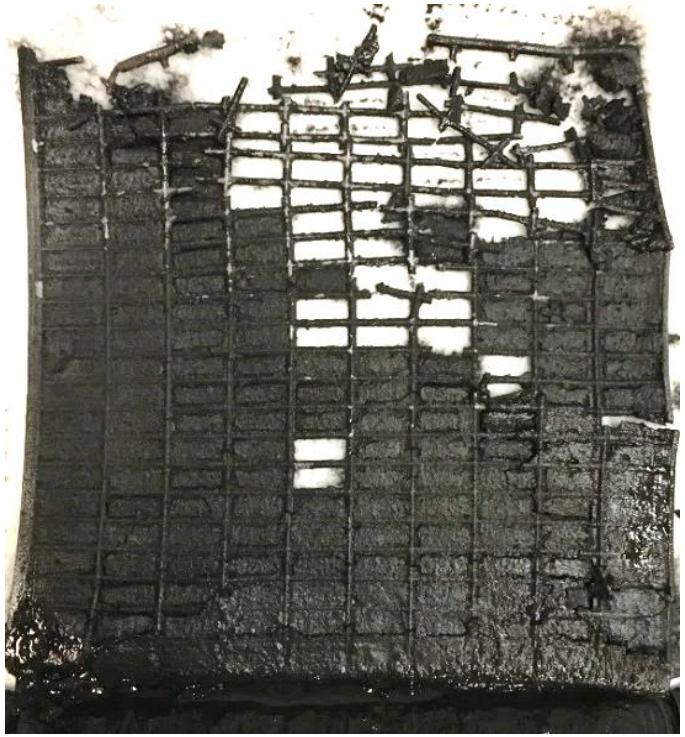
Retained Structure at End of HOT Cycle Life

- **SAE-J240 @ 70C = High-temperature, abusive study mimicking automotive battery operating conditions**
- **Altered Failure Modes:**
  - Control batteries failed by NAM growth, shorting, PAM collapse
  - Batteries with MR completed 60% more cycles and the active material is better intact with less corrosion

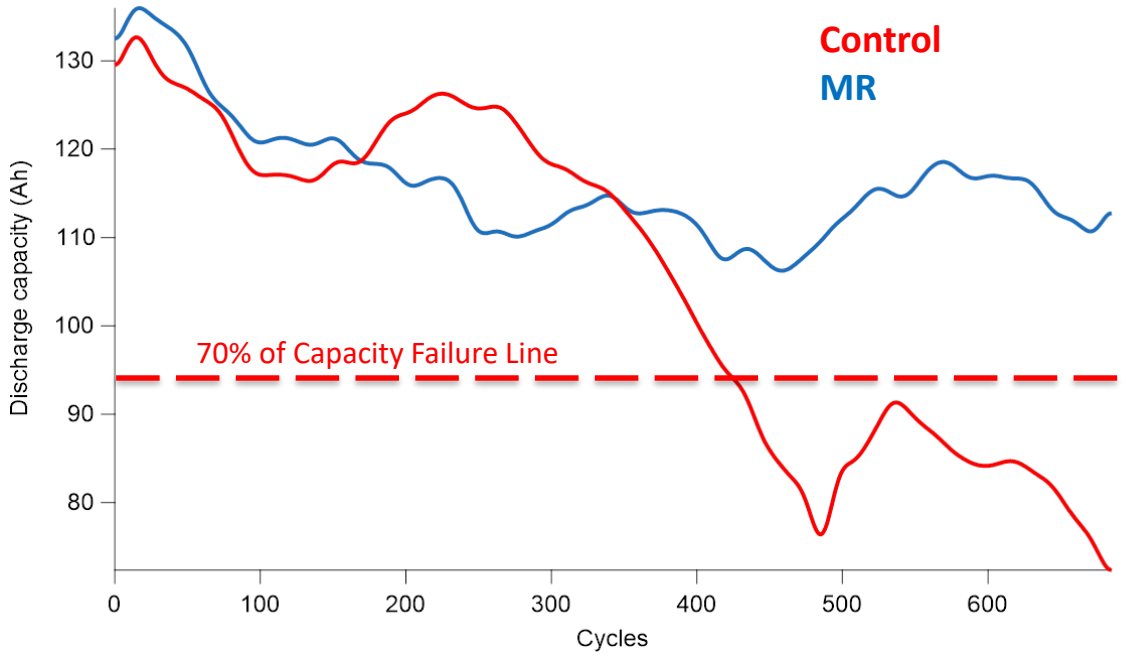
Control Positive

MR Positive



Synergy of Efficient Charging + Reliable Microstructure

Decentralized Rural Electrification (DRE) Test



Step	Mode	Protocol	Cycles	Potential Failure
1	Preparation	1) Fully charge the battery 2) Discharge at C/10 A till 10.5V		
2	Undercharge cycles	1) Charge at C/10A till 14.1V 2) Rest for 3 hrs 3) Discharge at C/10A till 10.5V 4) Rest for 3 hrs	5	Acid stratification Sulphate growth AM shedding
3	Overcharge cycles	1) Charge at C/10A till 120% Capacity 2) Rest for 3 hrs 3) Discharge at C/10A till 10.5V 4) Rest for 3 hrs	5	Corrosion Active Material loosening Sulphate growth Active Material shedding Waterloss
Repeat sequences 2 and 3 until discharge capacity in overcharge cycle drops below 70% of C/10 capacity				

- **DRE test replicates failure modes seen in real applications**
  - Water loss, corrosion, sulphation, active material shedding
- **Each cycle lasts ~24 hours**
- **MR is taking in more Ah per charge without increasing water loss**
- **MR delays long-term failure modes, extends lifetime >50%**
  - Control fails at 425 cycles. MR capacity has stabilized after initial break-in and continues to cycle without degradation beyond 550 cycles

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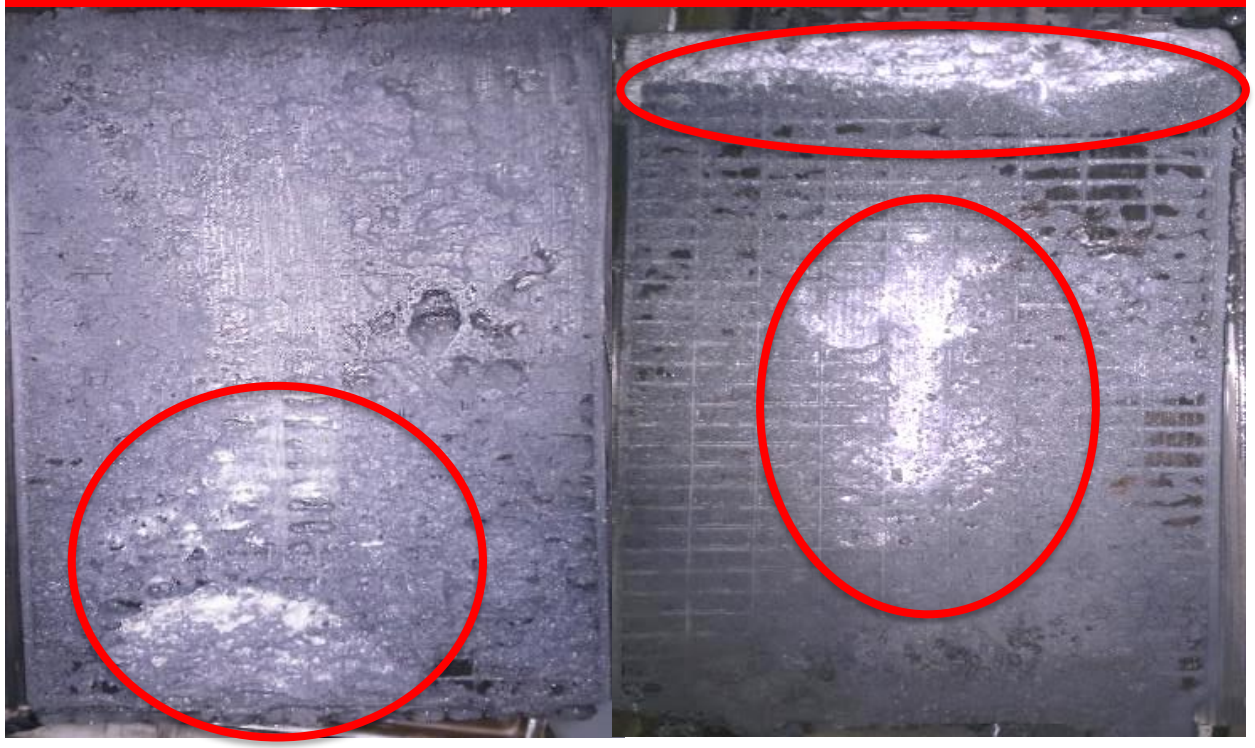
MR Suppress Sulfation, Maintain Capacity

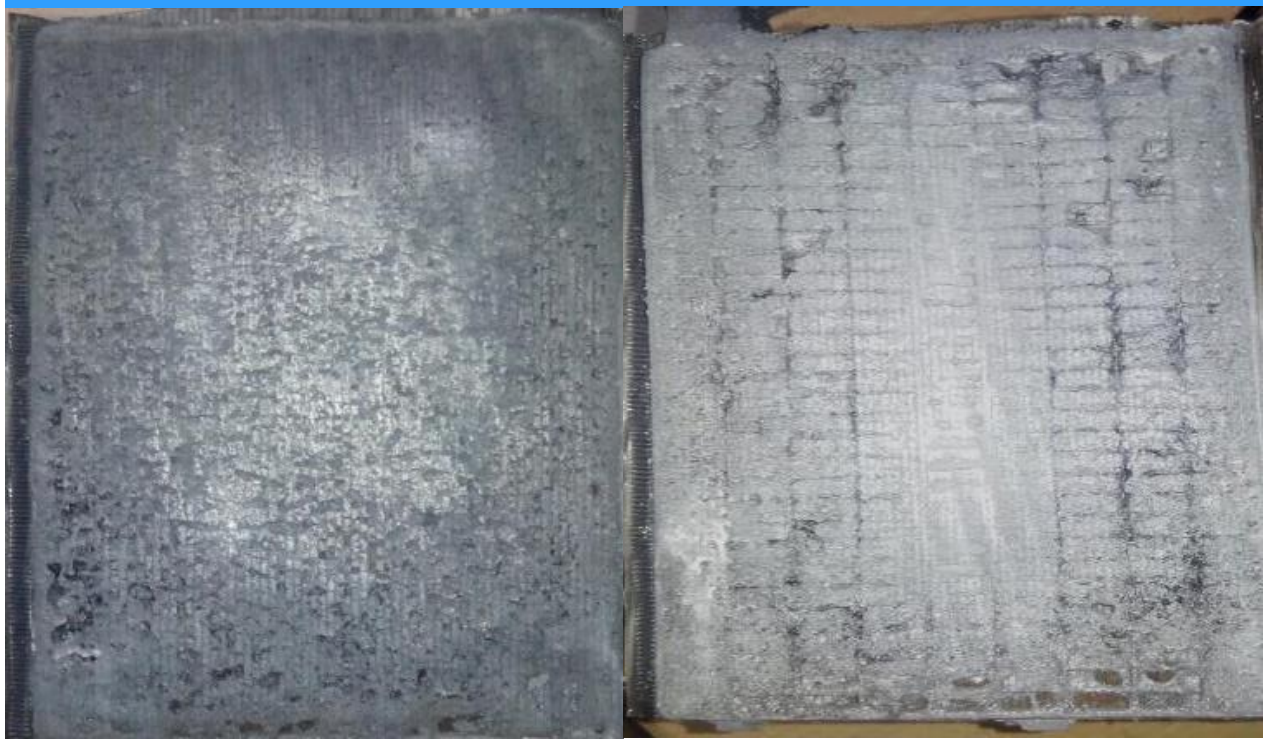
- DRE Test (Negative Plate Tear Down Plates)

Control



- Non-uniform material utilization
- Material soft and puffing/falling out
- Heavily sulfated surface
- Large insulative Sulphate crystals

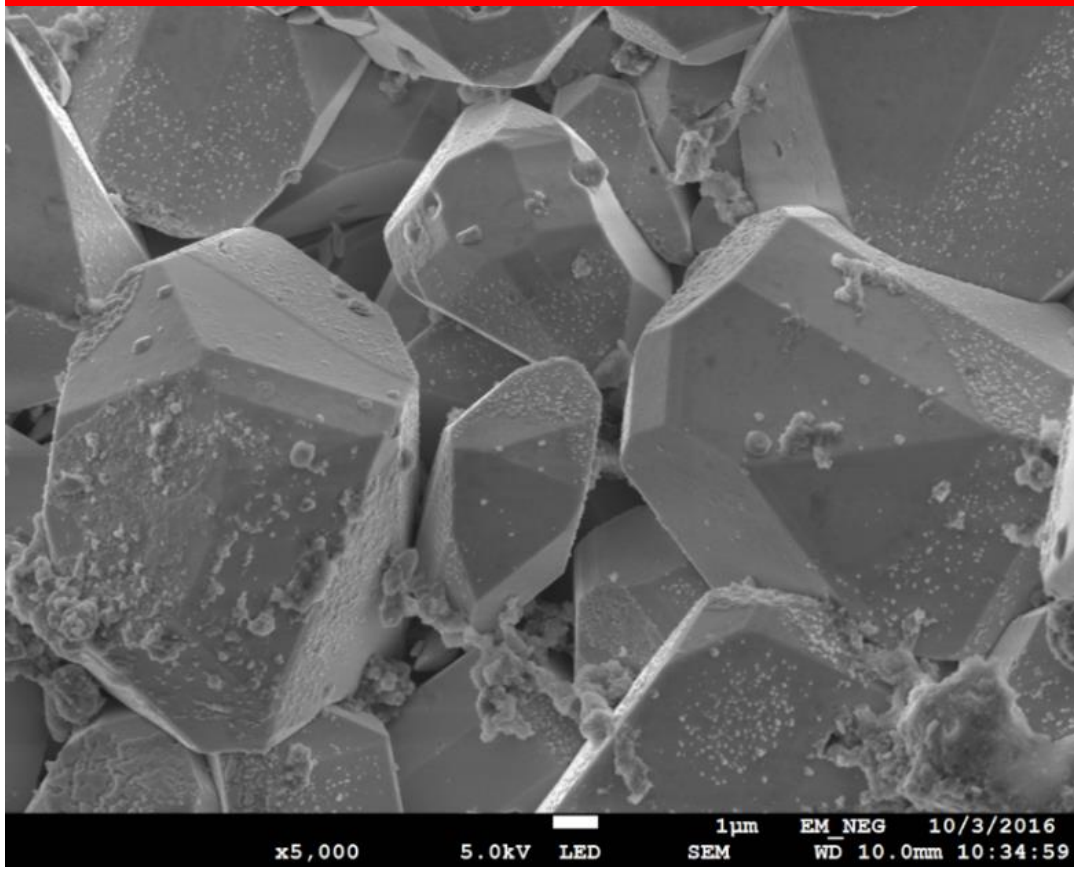
MOLECULAR REBAR®



- Smaller and uniformly sized crystals
- Shiny surface, plate still usable
- No sulfate present on surface

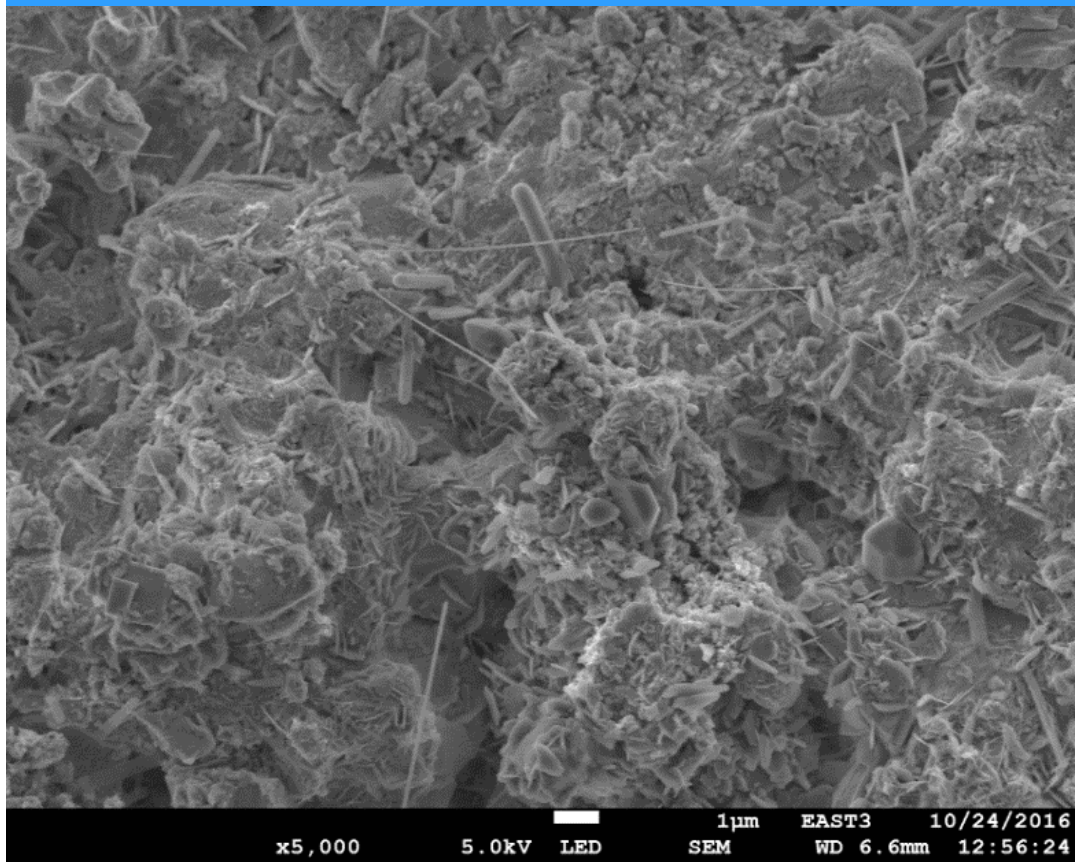
MR Preserve Microstructure throughout Life

Control Negative (Center Plate)



- Non-uniform material size
- **Major lead sulfate crystal growth**

MR Negative (Center Plate)



- More uniform material size
- **Minimal lead sulfate crystal growth**

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MOLECULAR REBAR® Summary

- **MOLECULAR REBAR® products made of dCNT are designed to be easily be incorporated into industrial pasting lines with minimal to no changes to recipes or equipment.**

- **MOLECULAR REBAR® Provide Similar Benefits Across Applications**
  - **More Efficient Charging with MOLECULAR REBAR®**
    - Reduced Recharge Times
    - More Consistent Capacity & Charge Acceptance
  - **Improved Maintenance of the Micro-Structures in PAM and NAM**
    - Sustains a more Effective Conversion of Active Material
    - Reduces and Suppresses Irreversible Sulfation