MOLECULAR REBAR®:
Discrete carbon nanotube additives for deep-cycle and stationary applications

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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®
Global Adoption - MOLECULAR REBAR® Technology

Global Adoption:

- Products Commercially Available and being sold to Lead Acid Battery Manufacturers
- Working with >100 battery manufacturers worldwide, each at various stages of development and/or commercial sales.
- Recent approval for use in major Automotive OEM batteries. (SLI)
- Have proven that Molecular Rebar can help battery manufacturers meet new OEM requirements for “Advanced Automotive Battery” applications.
- Large amount of data on full-scale production batteries, not just 2V hand-built cells
- Approved to discuss three Mfr’s publicly at this time (Eastman – India, Pacific Battery – Fiji, Tianjin Lantian Power Sources – China)

Why the rapid adoption?

- Technology is innovative, cutting-edge, and scientifically sound
- Cost effective performance improvements over a wide variety of applications
- Low risk to use
- No (or very low) capital expenditure by manufacturer; very easy to use and implement
- Highly technical staff works hand in hand with your company during ramp up.
- World-class technical support from Black Diamond Structures
MOLECULAR REBAR® Technology

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)

MOLECULAR REBAR® Technology Key Technical Advantage
About us: Product & Packaging

- Material is shipped as a black pourable liquid which is added directly to the paste mixer for both **NEGATIVE** & **POSITIVE** plates

- MOLECULAR REBAR® products are formulated for ease of use and incorporation

- Sold in 1,250L Totes, 200L Drums or 10L Jugs (750L / pallet).

- 9 Month Shelf life

- A volume of pasting water is replaced with the MOLECULAR REBAR® liquid so total liquid volume remains the same
MOLECULAR REBAR® Benefits For Your Battery

- Enhances Consistency of Performance
- Improves Charge Acceptance >25%*
- Increases Cycle Life 25-300%*
- Enables Partial State of Charge Operations
- Reduces Irreversible Sulfation & Plate Growth
- Enhanced Plate Durability
- Improves Thermal Operational Ranges
- Simple Integration Into Existing Processes

*Dependent on battery and test protocol
e-Rickshaw – Tubular Batteries: Pb2100 Series

• Product = Pb2100N

• Key Features:
  – Enable Flat Plate recharge times in Tubular
  – Delayed need for day-time charging
  – Reduced water consumption
  – Extended Cycle Life
  – More Consistent Capacity throughout Life

• Batteries provided by Eastman (80Ah Tubular)
Recharge Time Can be Dramatically Reduced

- eRickshaw batteries must be fully charged every night (8-14h)
  - Full recharge requires 110%+ of the last discharge Ah
  - Molecular Rebar® reduces time to 110% Ah by 25-35%
  - In the field, this allows an MR-rickshaw to reach 100% SOC well within an overnight period

**Protocols:**

**10A / 15.2V**
- Av. CON = 15.6h
- Av. MR = 12.0h

**15A / 15.2V**
- Av. CON = 10.2h
- Av. MR = 7.9h

**Protocol:** DCH 90Ah (55%DoD), CHR 100Ah

**Eastman 12V, 150Ah Tubular**
e-Rickshaw: Field Trial Voltage Log

Average Use until Recharge

Shaded Area Shows Charge Periods

- Standard batteries go ~5.25 hrs before charging
- **Pb2100N** batteries go ~11.0 hrs before charging
  - Field chargers used (see above images)

**Pb2100N** batteries allow a full day of use before needing to recharge
Deep Cycle – VRLA: Pb2300 Series

• Product = Pb2300N and Pb2300P

• Key Features:
  – Faster Recharge Times
  – More Consistent Capacity throughout Life
  – Extended Life

• Batteries provided by Tianjin Lantian Power Sources Company (6FM38 VRLA)
• Batteries tested by CETC18
>150% Increased Life in Aggressive 60% DOD Cycling

- Pb2300N/P enhances cycle life by over 150%
- Pb2300N/P batteries fully recharge to 105% of discharge capacity in ~4h, initially, but with further conditioning recharge in ~2h
- Controls fail to return full capacity in 8h and % capacity returned declines with age
- Pb2300N increases charge acceptance, maintains surface area, shifts negative potential, and reduces sulfation
- Pb2300P provides structural integrity and compensates for the shift in negative potential

Protocol: 60% DoD C10DCH, 8h/105% Ah-return CHR, cycle until EoDV < 10.5V, Boost, Check C10
Failure: C10 measurement after cycling and boost fails to return >80% of initial value
Solar – Flooded: Pb3200 Series

• Product = Pb3200N

• Key Features:
  – Reduced Deficit Charging
  – Extended Life
  – Faster Recharge Times
  – Lower Water Consumption

Batteries provided by Eastman (150Ah Tubular)
Solar: DRE Life Cycle Results

Decentralized Rural Electrification (DRE) Test

- DRE test replicates failure modes seen in real applications
  - Water loss, corrosion, sulphation, active material shedding

- Each cycle lasts ~24 hours

- Pb3200N delays long-term failure modes, extends lifetime >50%
  - Control fails at 425 cycles. Pb3200N capacity has stabilized after initial break-in and continues to cycle without degradation beyond 550 cycles
  - Pb3200N is taking in more Ah per charge without increasing water loss

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<table>
<thead>
<tr>
<th>Step</th>
<th>Mode</th>
<th>Protocol</th>
<th>Cycle(s)</th>
<th>Potential Failure</th>
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</table>
| 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  
Water loss |

Repeat sequences 2 and 3 until discharge capacity in overcharge cycle drops below 70% of C/10 capacity
Pb3200 Series: DRE Life cycle test (Tear Down Plates)

Control Negative (Center Plate)

- Non-uniform material utilization
- Soft material can easily be wiped
- Heavily sulfated surface

Pb3200N Negative (Center Plate)

- Shiny surface, plate still usable
- No sulfate present on surface
Pb3200 Series: DRE Life cycle test (SEM of Tear Down Plates)

Control Negative (Center Plate)

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

Pb3200N Negative (Center Plate)

- More uniform material size
- No lead sulfate crystal growth
Pb3200 Series: DRE Life cycle test (SEM of Tear Down Plates)

Control Positive (Center Plate)

- Positive has disintegrated

Pb3200N Positive (no MR) (Center Plate)

- Positive is intact where MR was present in the NAM
Solar (PSOC)- VRLA: Pb3300 Series

• Product = Pb3300N and Pb3300P

• Key Features:
  – Enhanced PSOC Performance
  – Extended Life
  – Reduced “Refresh” Charging
  – More Consistent Capacity throughout Life

• Batteries provided by Tianjin Lantian Power Sources Company (6FM38 VRLA)
• Batteries tested by JBI Corp, Genoa, Ohio USA
HRPSoC @ 50% SOC Cycling Improvements

• Pb3300N 200% More Cycles
• Pb3300N/P 288% More Cycles

Despite a slightly higher initial capacity, Control batteries cannot maintain their capacity between HRPSoC micro-cycling segments
• Pb3300N and Pb3300NP have consistent capacity

Protocol: Fully charge battery, determine initial C/1 Capacity, Recharge, Discharge to 50% of initial capacity, begin micro-cycling [22.8A for 6 mins, 5min rest, Charge at 22.8A for 6 mins, rest for 5mins, repeat until DCH<10.2V, CHR>14.7V], determine remaining C/1 Capacity, Repeat until capacity drops below 50%
Summary

MOLECULAR REBAR® is a battery performance-enhancing additive comprised of discrete carbon nanotubes, which are uniformly dispersed within negative and/or positive battery pastes via an aqueous solution.

- **Deep-Cycle Batteries** with MOLECULAR REBAR® show:
  - Reduced charging times
  - Flexibility in charging protocols
  - Significant Improvements in Cycle Life

- **Stationary Batteries** with MOLECULAR REBAR® show:
  - Improved performance consistency
  - Longer Cycle Life in PSoC operations
  - Longer Cycle Life in severe cycling conditions

**Formulated products available for:**

- **Automotive**
  - Conventional Flooded: Pb1100 Series
  - Enhanced Flooded: Pb1200 Series
  - Advanced Automotive VRLA: Pb1300 Series
  - 2-Wheeler Automotive VRLA: Pb1400 Series

- **Deep Cycle / Motive**
  - Flooded e-Rickshaw: Pb2100 / Pb2200 Series
  - VRLA for Mobility Assistance: Pb2300 Series

- **Stationary**
  - Inverter Flooded: Pb3100 Series
  - Solar Flooded: Pb3200 Series
  - Renewables VRLA: Pb3300 Series
THANK YOU FOR YOUR ATTENTION!

Please Visit Us at Booth #50

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