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Combining Separator and Active Mass Improvements to Augment Charge Recovery

Abel Sy, Paul Everill**, and Eric Miller**

05-16-26

Better Charge Recovery with Additives and Separators

Charge Recovery (CR) is a key metric promoting Pb-Acid for AUX use over other chemistries

Global research suggests that NAM and PAM modifications are critical for AUX-CR improvement

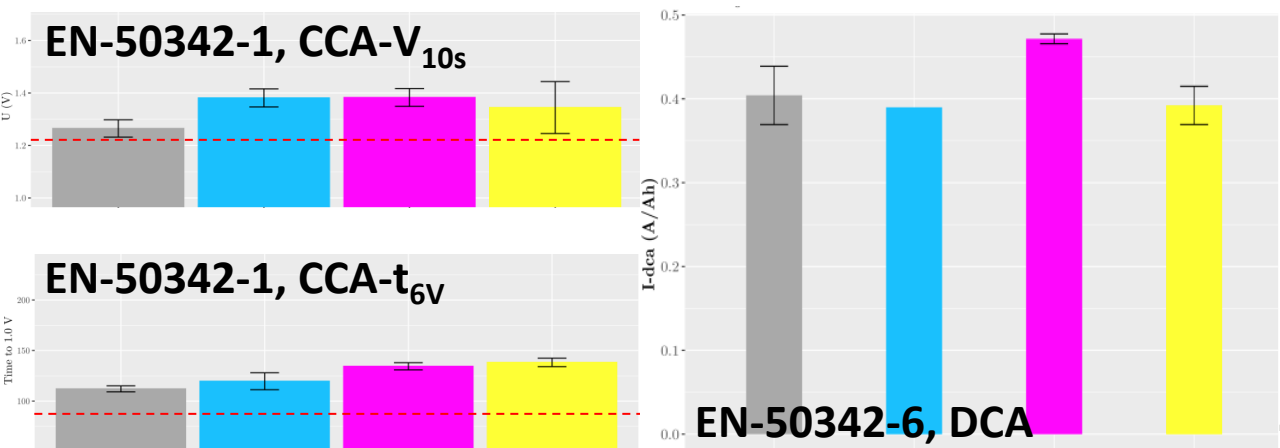
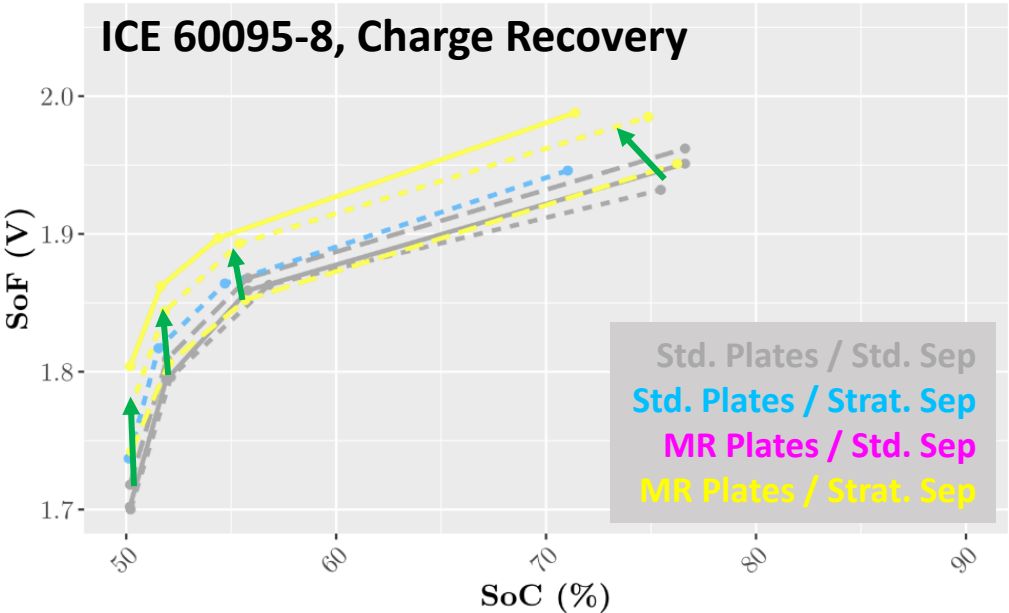
- Strong charge acceptance (i.e., NAM)
- Reliable/predictable pulse power (i.e., PAM)

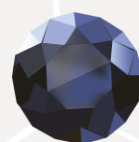
We suspected that AM additives combined with acid-storing separator technology could synergize

- MOLECULAR REBAR® nanomaterials in NAM/PAM
- Stratosphere™ separator wrapped NAM

Findings

- Synergies confirmed in V_{10s} SoF improvements
- Positive / neutral metrics in characterization tests





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Impetus For Research

IEC 60095-8 Charge Recovery (CR) is a newly codified test specification that challenges batteries

- Judges failure to recover adequate charge (SoC) during worst-case cold conditions
- Judges failure to recover adequate function (SoF) during worst-case cold conditions

In previous Charge Acceptance tests (EN 50342-1/6, SAE, IEC, OEM) NAM improvements took spotlight

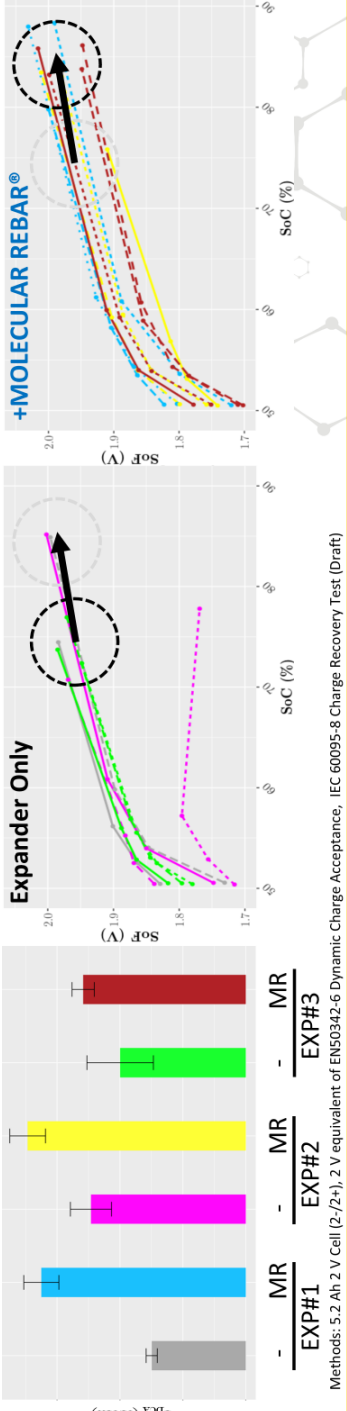
Global research suggests that NAM and PAM modifications are critical for CR improvement

- Strong charge acceptance (i.e., NAM)
- Reliable pulse power and/or capacitance (i.e., PAM)

Prior Evidence that Additives Support CR Performance

BDS helps you understand new AUX specs, thanks to our engagement w/ IEC discussion groups, ALBA

- Internally, we are currently focused on providing excellent charge recovery, without any detriments
- This 2 V work combines MOLECULAR REBAR® with new expander components from our partners
- Targeting higher DCA and improved SoF recovery per unit SoC (further up, right, charts below)



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Direction

Black Diamond + Daramic believe that combining our technologies will create significant CR benefits



Black Diamond Structures

- MOLECULAR REBAR® (MR) products known to alter and control crystal structure in NAM and PAM
- Products support improved charging, PSoC reliability, deep discharge recovery, and process efficiency



- High-performance separators that supercharge PbA batteries with durability, efficiency, and long life
- Stratosphere™ technology leverages gelation layer to preserve concentrated acid at plate surface for improved charging, PSoC Reliability, and extended cycle life, bridging the gap between AGM and FLD

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Application Relevance

1) Cost Reduction: How Does Your Work Allow Battery Makers to Do More, With Less?

- Increased performance is often a result of higher AM utilization, opening possibilities for downsizing
- MR performance benefits can permit 5-10% of active material to be removed while reducing process costs
- Stratosphere™ performance can be similar to AGM, for non-AGM prices and zero capital investment

2) OEM Engagement: How Does Your Work Benefit the End User (OEM's Customers)?

- MR crystal control processes lead to capacity/crank/voltage consistency over life
 - Increases predictability, reliability, functional capability
- Stratosphere™ reduces stratification and improves cyclability
 - Reduces warranty return chance

3) Competition: How Does Your Work Increase Pb-Acid Competitiveness?

- If MR and Stratosphere™ can successfully elevate Pb-Acid capability in a cost- and/or weight-reduced package, we will gain further defense against Na⁺/Li⁺ systems

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CR22:ALBA26

Test Plan

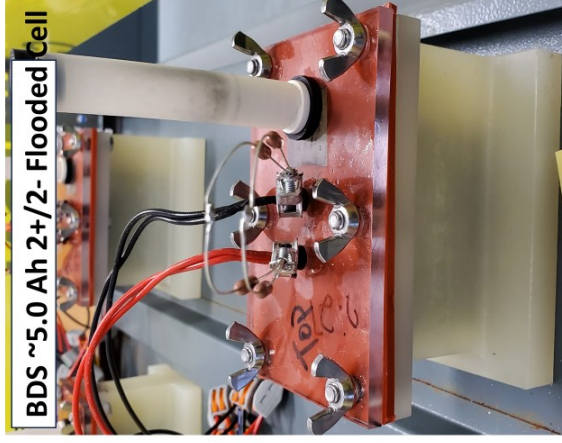
Variables under test (n=3)

- #1: CON+/CON- w/ Std. Separator
- #2: CON+/CON- w/ **Stratosphere™**
- #3: **MR+**/MR- w/ Std. Separator
- #4: **MR+**/MR- w/ **Stratosphere™**
- Other components: Automotive expander, 4BS cure

Electrical Testing

- Formation (2-shot)
- 2x C₂₀ (EN 50342-1)
- CCA (EN 50342-1)
- DCA (EN 50342-6)
- Water consumption (SAE J537)
- Charge Recovery (IEC 60095-8)
- Cycling (EN 50341-6 50%-bulb) – *still in progress*

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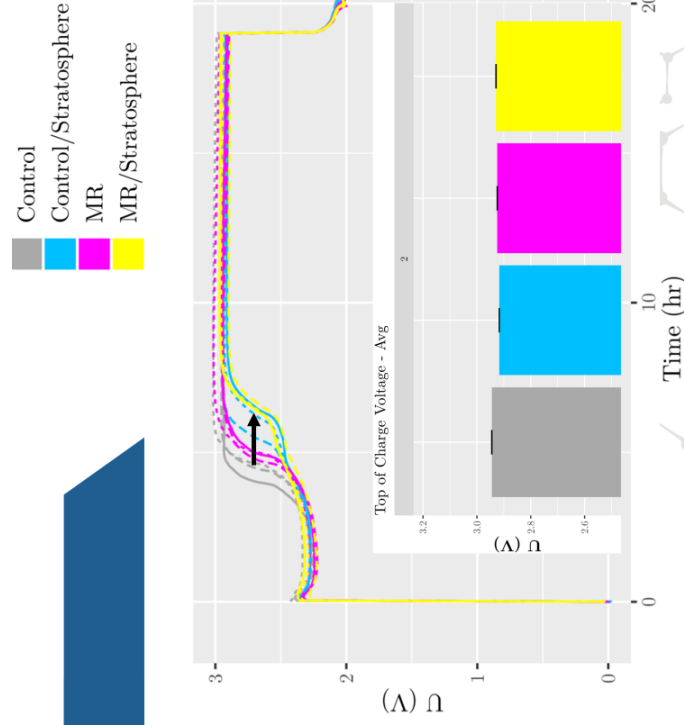
Formation

Protocol

- CHR: 1 A for 19h, rest (1.15 g)

Results

- **12/12 cells formed as expected**
- Delay in climb to ToCV with Stratosphere™
 - Due to modified acid access?
 - May prove beneficial to PAM
- ~30-40 mV lower ToCV w/experimental variables
 - Expected with MOLECULAR REBAR® in negative



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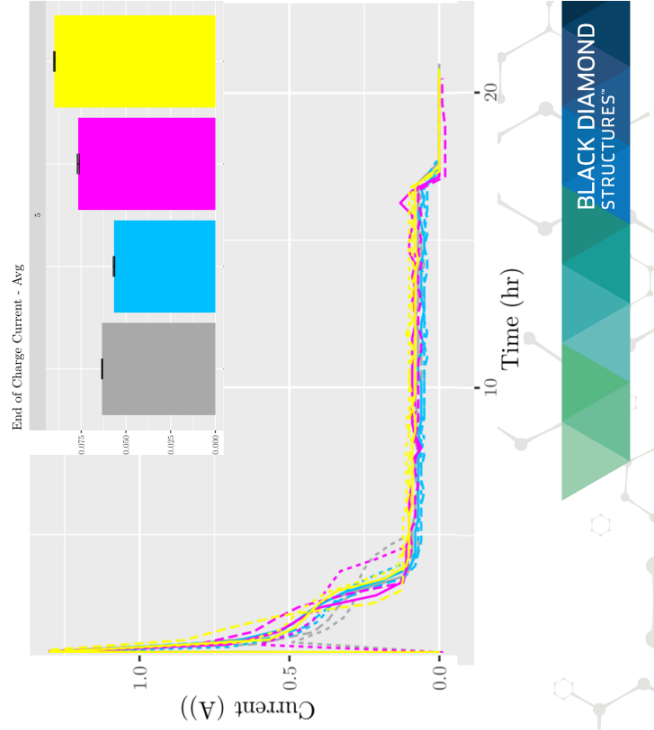
Boost

Protocol

- CHR: 16 V for 16h (1.15 sg)

Results

- Boost finishes formation, minor Ah-in
- Lower and higher EoCC seen w/Stratosphere™
 - Indication of BDS/Daramic product interaction?
- Slightly higher EoCC w/ MOLECULAR REBAR®
 - Expected



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2x C₂₀ Capacity Checks

Protocol

- DCH: 0.26 A to 1.75 V (1.285 sg)
- CHR: 1.3 A / 2.67 V for 20h, or 130% return

Results

- Tight capacity measurements
 - ~5.0 Ah based on industrially produced PAM
- ~12% faster charge time w/ MR, Stratosphere™
- EoCC increase with MR and Stratosphere™
 - 2nd C₂₀ considered more indicative of mature cell



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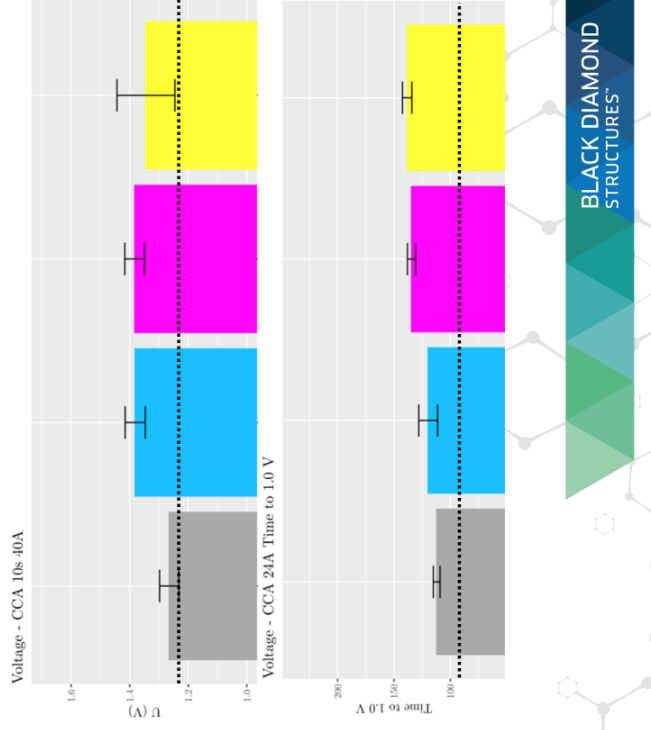
CCA Measurement

Protocol

- RST: -18 °C
- DCH: 42 A for 10s, rest for 10s, 25.2 A until V<1 V
- CHR: 1.3 A / 2.67 V for 20h, or 130% return

Results

- All cells meet CCA requirements
- MR and Stratosphere™ both increase V_{10s}, t_{6V}
 - Expected of MOLECULAR REBAR®
 - Surprise with Stratosphere™, where SAE-CCA show passing, but attenuated performance



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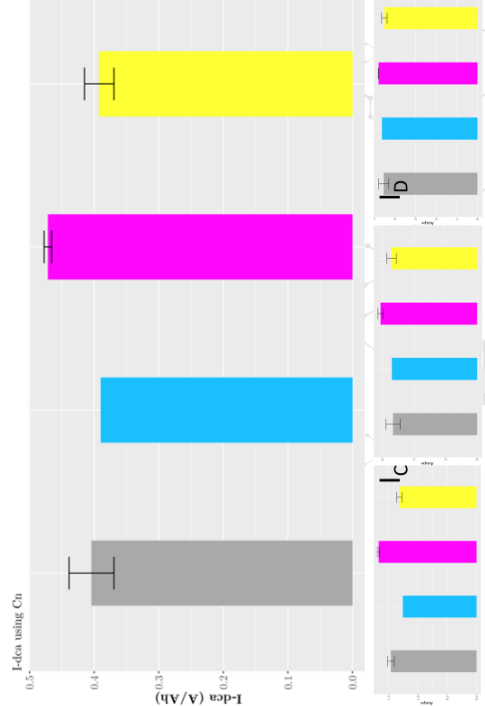
DCA Measurement

Protocol

- EN 50342-6 Dynamic Charge Acceptance
- 2V scaled

Results

- Stratosphere™ alone has no effect on I_{bCA}
 - Expected
- MR alone increases I_{bCA}
 - Expected



Water Loss Measurement

Protocol

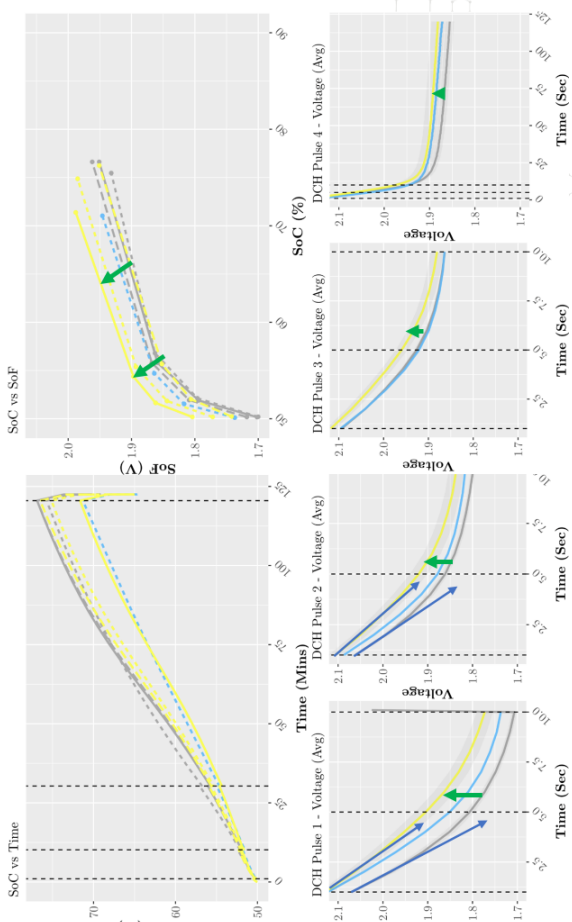
- SAE-J537 Water Loss Characteristic

Results

- Stratosphere™ synergizes w/ MR, lowers H₂O loss
- Needs confirmed on 12 V scale



Charge Recovery Measurement



Protocol

- IEC 60095-8 Charge Recovery

Results

- SoC recovery similar in early s
- Stratosphere™ improves SoF
- MR data lost due to broken fridge
- MR[®]+Stratosphere™ synergize to improve SoF more significantly
 - Pseudocapacitance slope change
 - Blue arrows
 - 0.18-0.30 V improvement (6 cell)
 - Green arrows

Cycle Life Performance

Protocol

- EN 50341-1:2015 50% DoD (no bulb)

Results

- *Pending...*

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Wrap Up

Conclusions

- MOLECULAR REBAR® and Stratosphere™ synergize to improve Charge Recovery for AUX batteries
 - SoF improvement of ~0.2-0.3 V_{10s} (6-cell equivalent)
 - *Stratosphere™ alone also supports increased SoF recovery*

- MOLECULAR REBAR® improves base performance and cycling, as expected – positive changes to AM
 - Benefits from Stratosphere™ reduce water consumption

- Stratosphere™ has no deleterious effects on base performance, as expected – positive changes to system
 - Expected to play a strong role in low-acid/stratification-based failure mode mitigation (i.e., cycling)

Future Directions

- 12 V validation with industrially-optimized separator compression to validate and expand value proposition
- Evaluation in Energy Storage and Deep Cycle applications where synergisms may be of even greater value
- Cost-Benefits analysis: FLD+MR+Strat < VRLA ?

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Thanks!

Contact Information:

Paul Everill – Chief Technology Officer, BDS – peverill@bd-structures.com

Serubbabel (Abel) Sy – Sr. Research Scientist, Daramic – abel.sy@daramic.com

Eric Miller – Sr. Director of Technology – emiller@daramic.com