Transforming Lead-Acid Battery Performance: Enabling Short-Time Constant Current Charging via Lead–Carbon Composite Incorporation

National Formosa University, Taiwan
Department of Materials Science and Engineering
Associate Prof. Shu-Huei Hsieh

Sep 2-5, 2025

over 11,000 students
4 colleges,
20 departments

- **Vision :** Tech and engineering with hands-on learning and innovative Research and Development

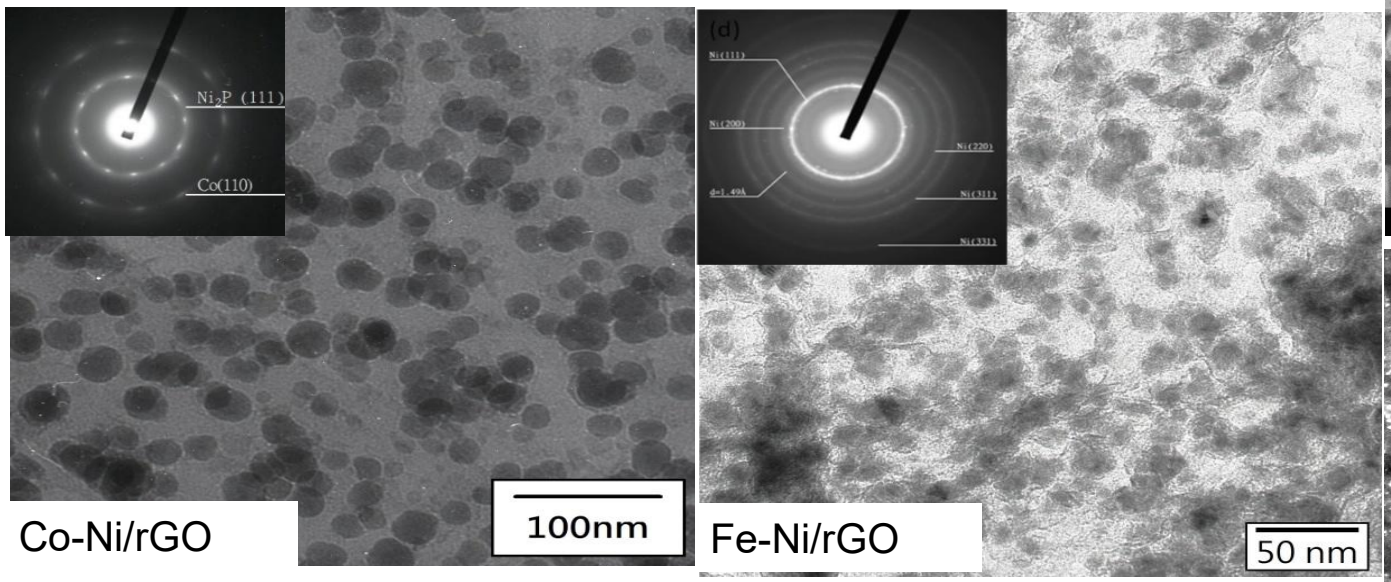
- **Positioning** : Engineering – focused, blending theory and practice, connected with industry and entrepreneurship.

National Formosa University _NFU

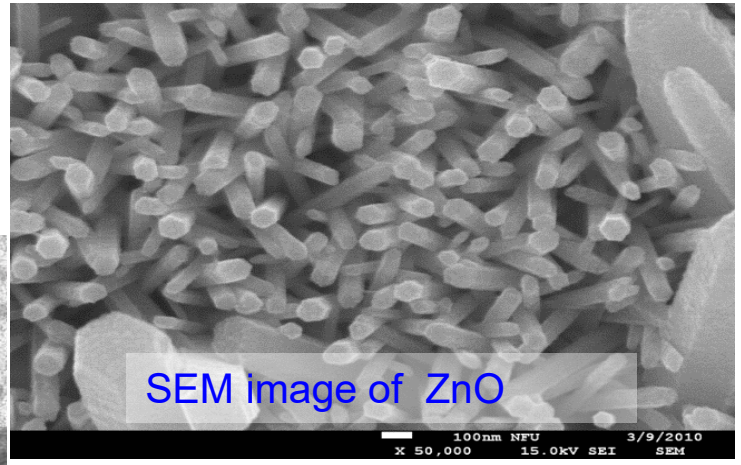
Introduction of Nano Materials Lab

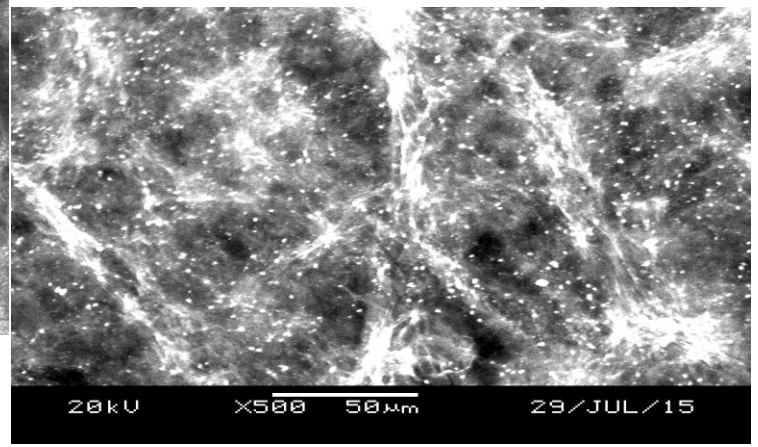
PI: Shu-huei Hsieh
Department of Materials Science & Engineering

- **Synthesis of nanoparticles, nanorods, nanowires, GO by wet chemical method(electro-electroless plating, sol-gel, hydro-thermal method etc.)**
- Modification of Carbon Materials
- Lead Carbon Fiber Composite (LCF)



TEM photos of bimetal/graphene





SEM image of Pb/graphene

Introduction of Nano Materials Lab

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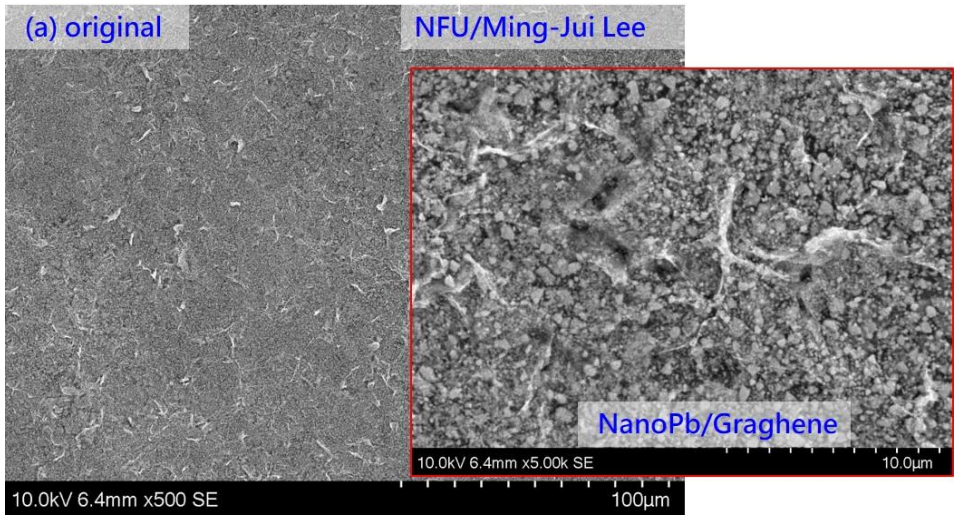
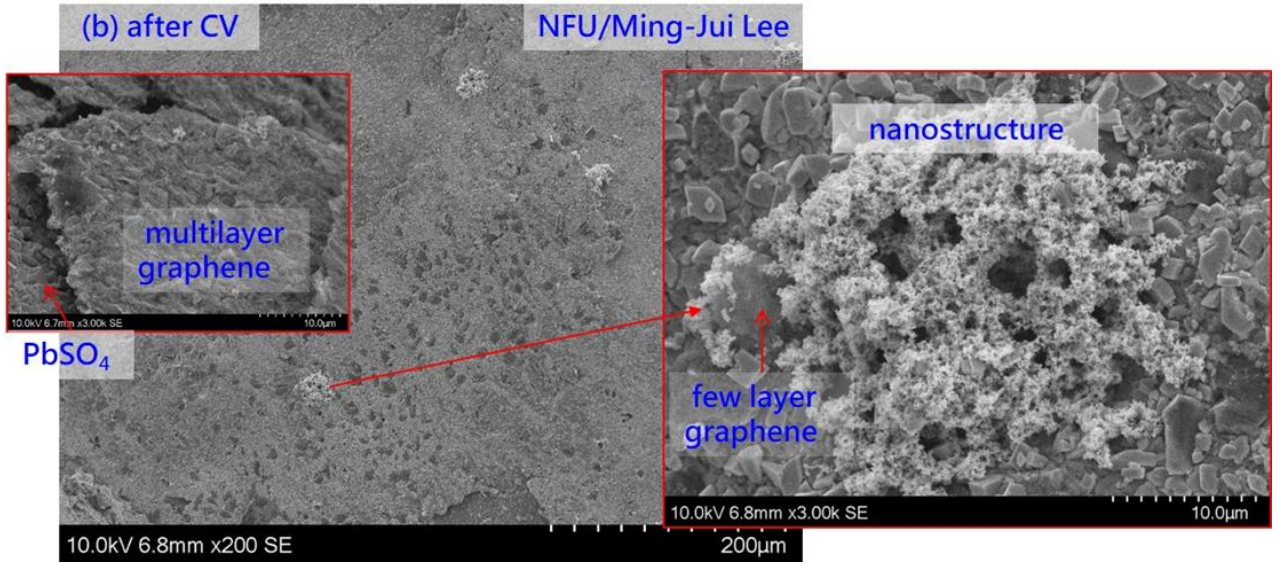
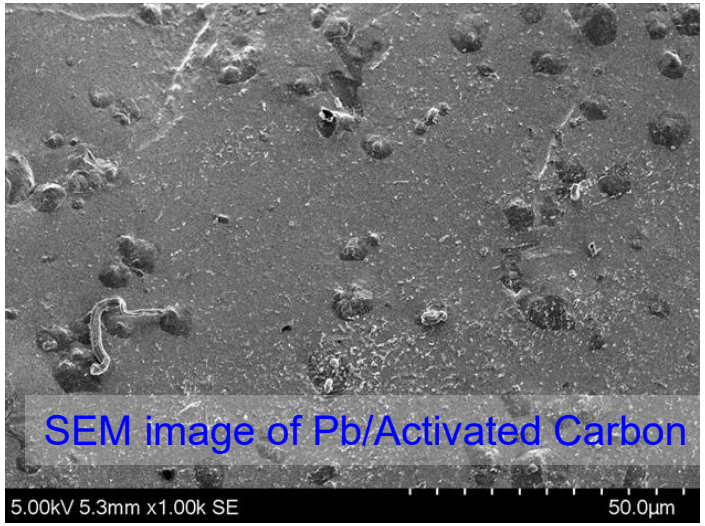
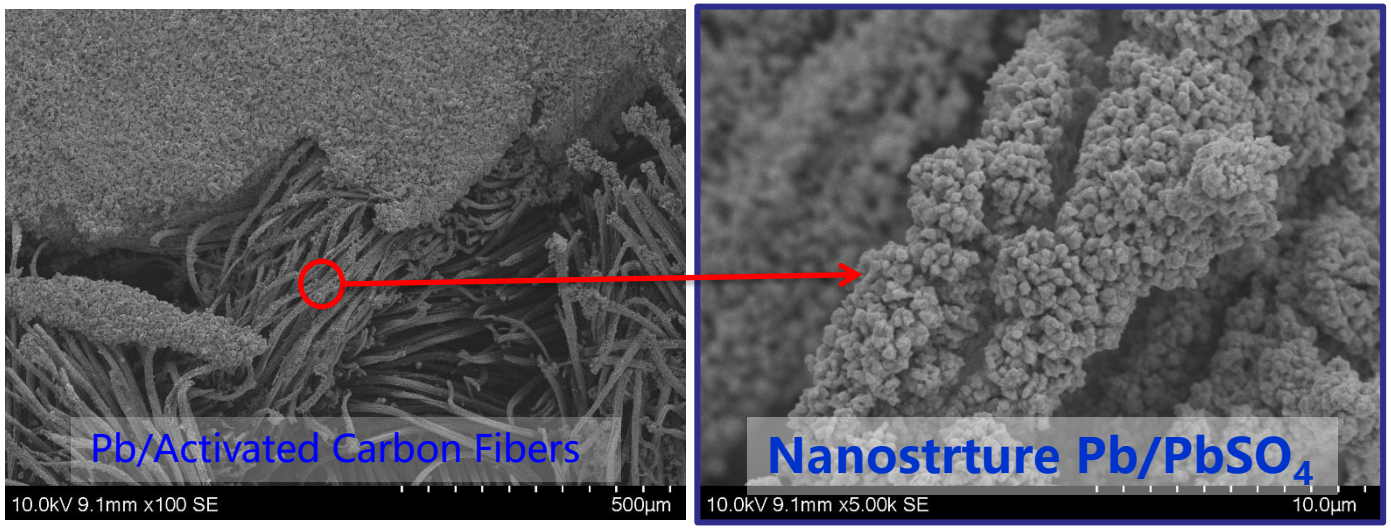
Department of Materials Science & Engineering

➢ Lead Carbon Composite (LCC)









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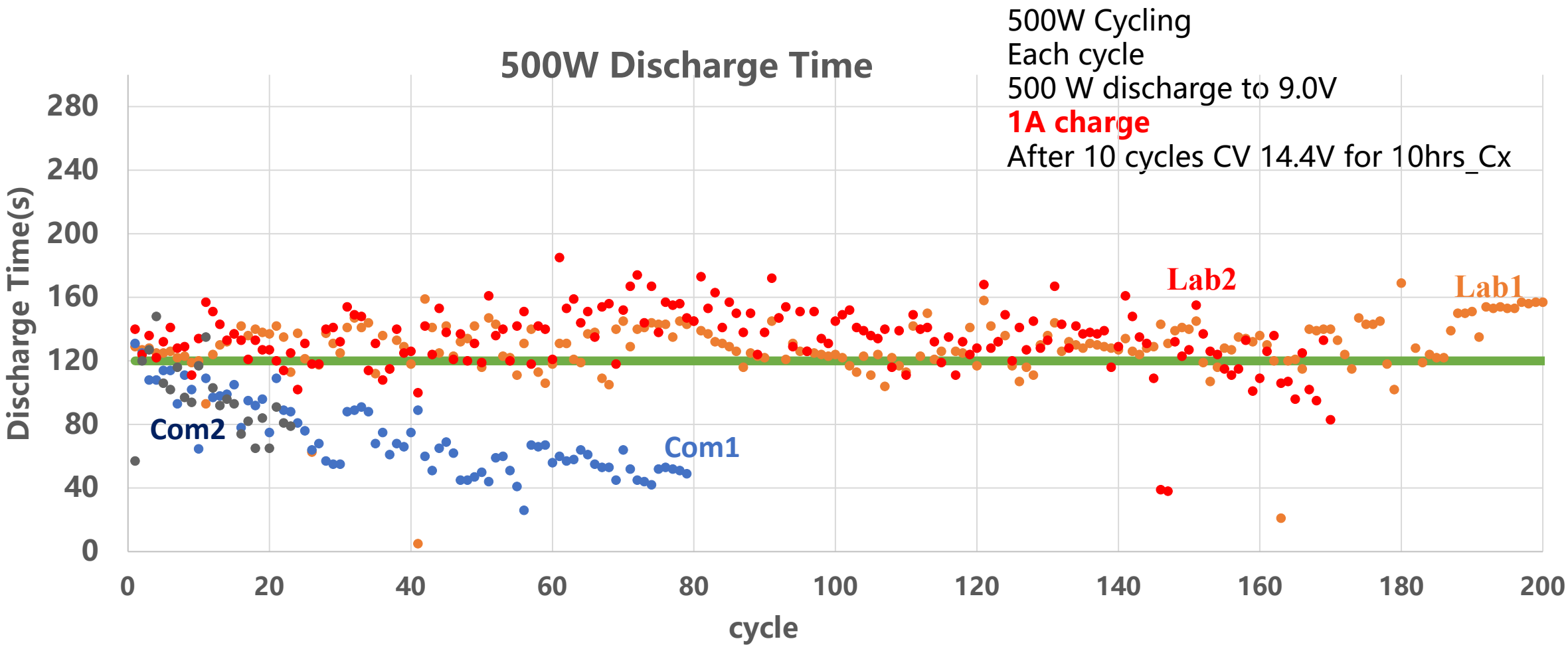
Outline

1. Performance of Lead-Acid Batteries with LCF Inserts
2. Why Use CF cloth applied in Lead-Acid Batteries?
3. Field Application of Lead-Acid Batteries with LCF inserts
4. LCF-Based Lead-Carbon Battery Design
5. Conclusion

Lab Battery(12V6AH) vs Commercial Battery (12V7AH)



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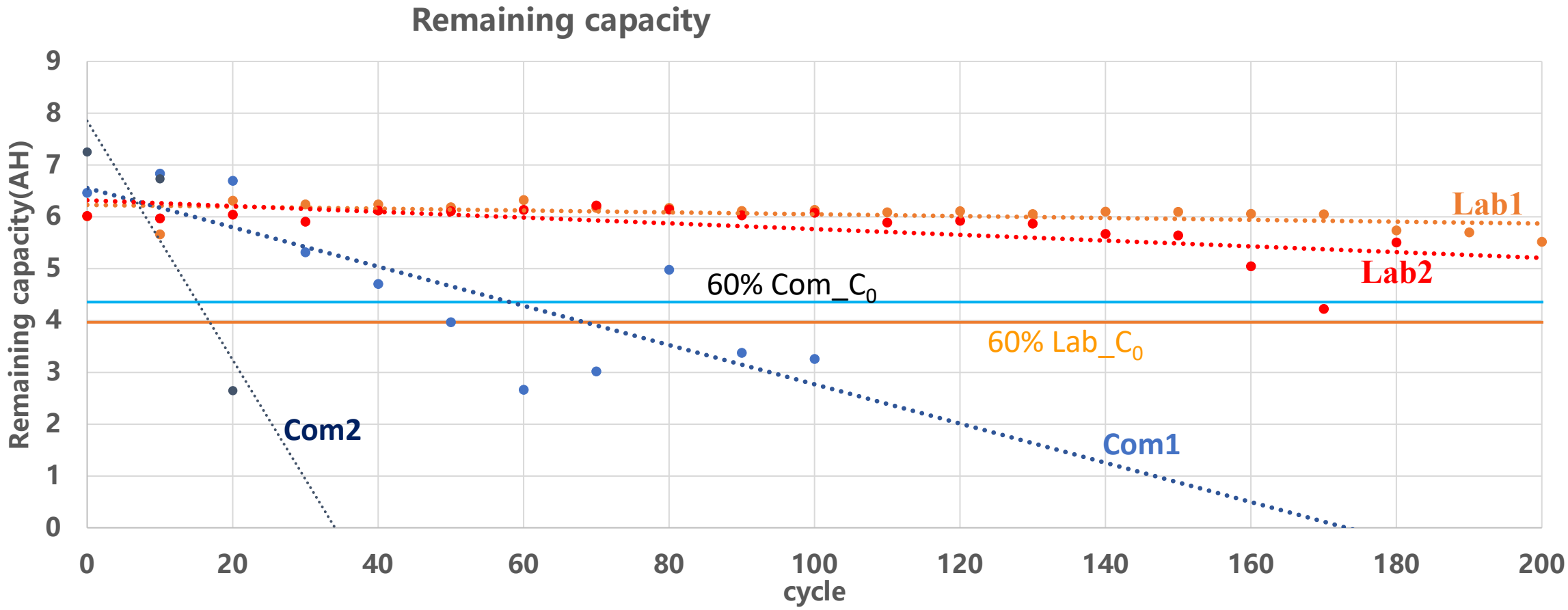
Lab Battery(12V6AH) vs Commercial Battery (12V7AH)

Lab:240 cycles consistent discharge time & remaining capacity 100%
Com:80 cycles decay discharge time & remaining capacity 41%



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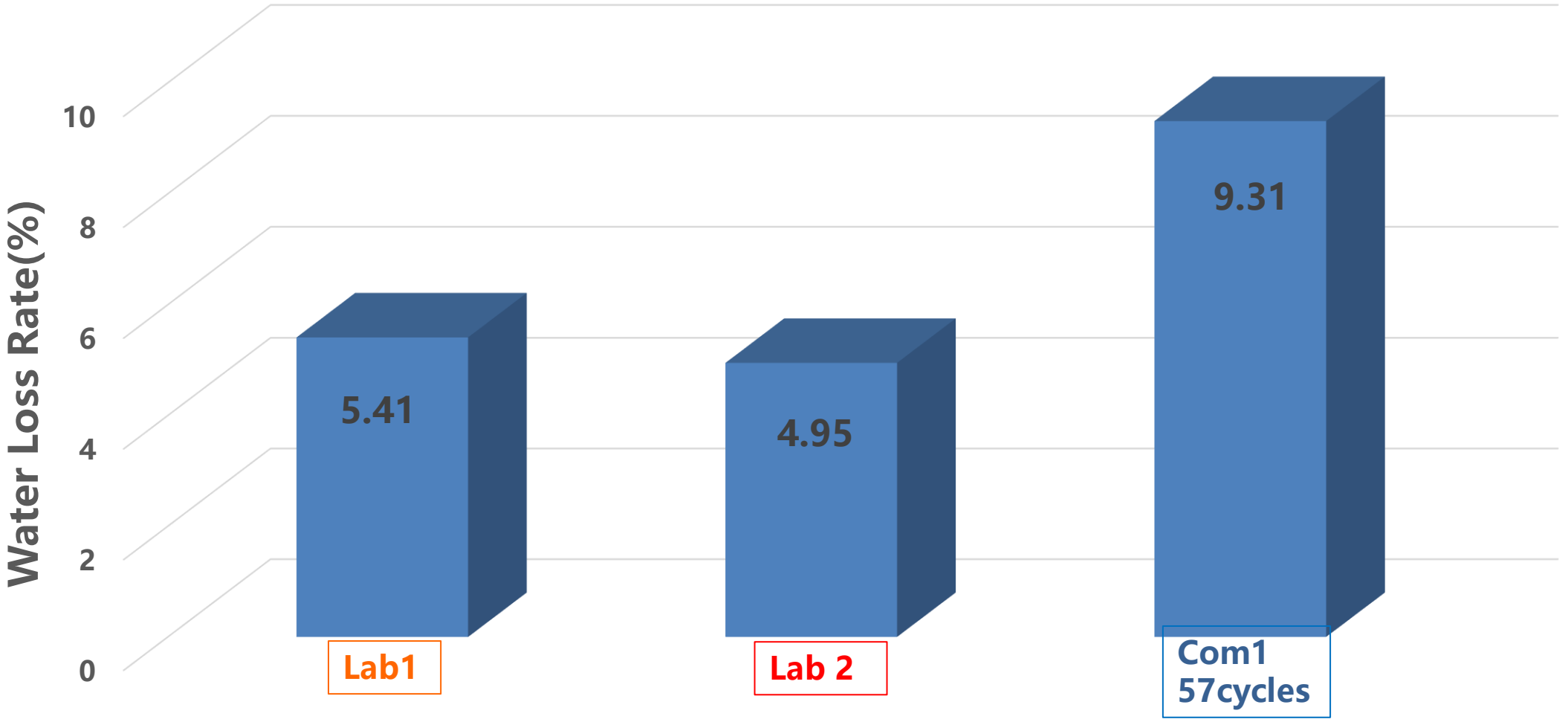
Water loss after constant 500W Discharge for 1st 60 cycles



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CF cloth applied in Lead-Acid Batteries

Why commercial batteries decay?

Constant current charging 1A (about 0.17C) was used to compensate for the energy lost during a 500W discharge to 9.0V, which may leave residual $PbSO_4$.

? Why do both Lab 1 and Lab 2 maintain the same discharge duration?

Lead-Acid Batteries with LCF Inserts

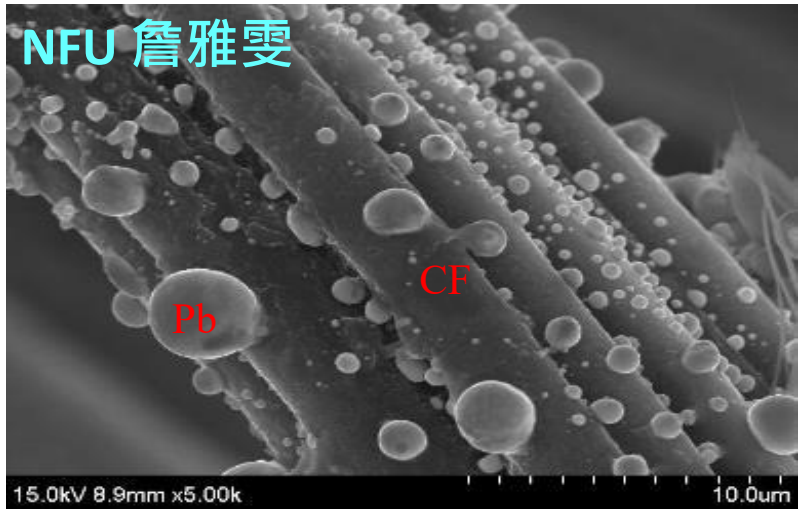
Lead – Carbon: Low Interaction Energy

Table 1. Surface tensions of various liquids and their wetting ability of nanotubes

Element/ compound	Surface tension (mN/m)	Wetting	Reference
HNO_3	43	Yes	[15]
S	61	Yes	[7]
Cs	67	Yes	[7]
Rb	77	Yes	[7]
V_2O_5	80	Yes	[14]
Se	97	Yes	[7]
Pb oxides	(PbO ~132)	Yes	[11]
Bi oxides	(Bi_2O_3 ~200)	Yes	[12]
Te	190	No	[7]
Pb	470	No	[7]
Hg	490	No	[7]
Ga	710	No	[7]

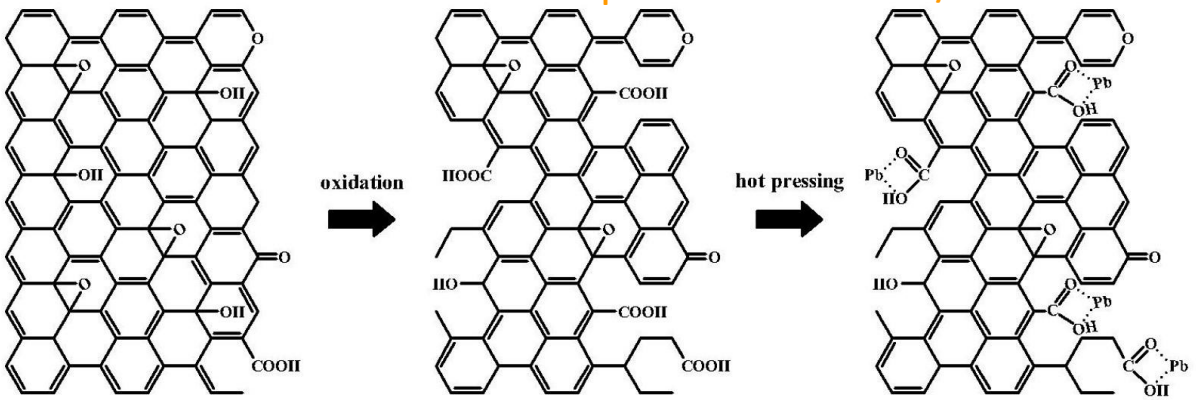
Ebbesen, J. Phys. Chem. Solids, 57, 951, 1996

$\gamma_{Pb} > W_{Pb\text{-}C}$ → $\theta > 90°$

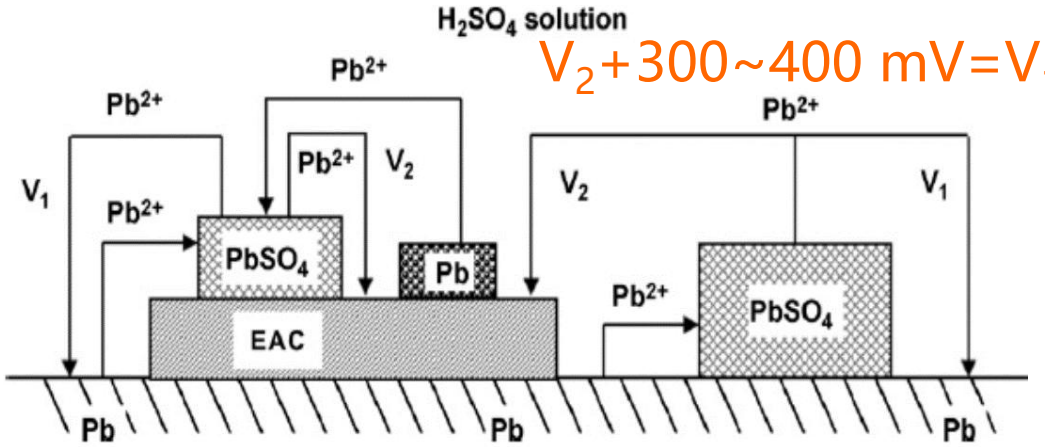


Adding EAC_Highly catalytic effect on the charge reaction

Schematic of the formation process of the Pb/CF bond



Ref: S.H. Hsieh etc"Application of carbon fibers in thin-plate pure lead batteries", Journal of the Taiwan Institute of Chemical Engineers 152(2023), P105175.

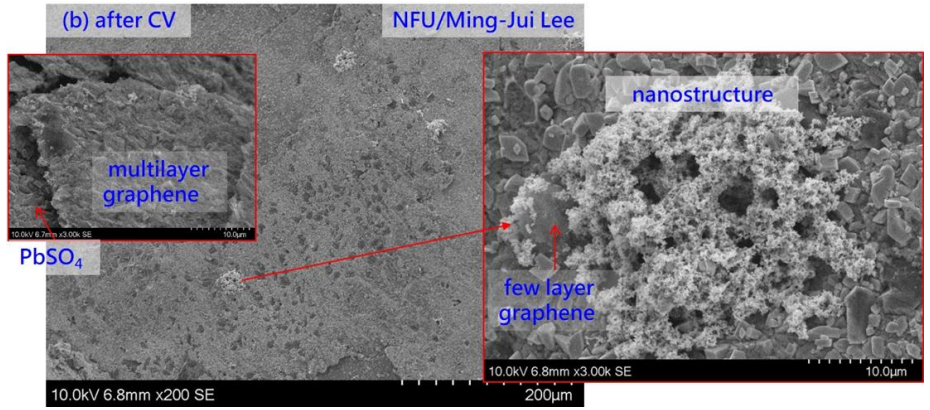


Ref: D. Pavlov etc. " Mechanism of action of electrochemically active carbons on the processes that take place at the negative plates of lead-acid batteries "，191 JPS 2009.

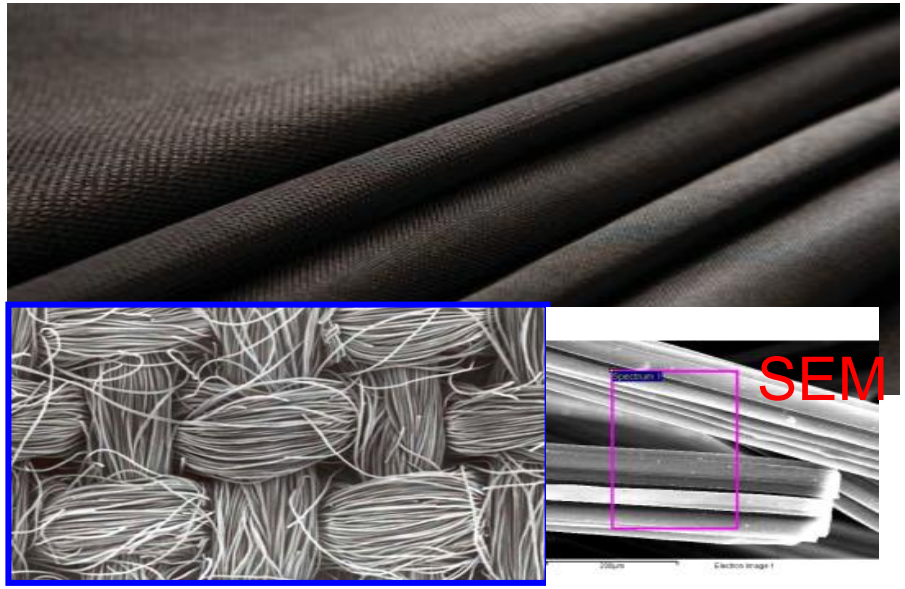
Lead Carbon Cloth Composite

To Be

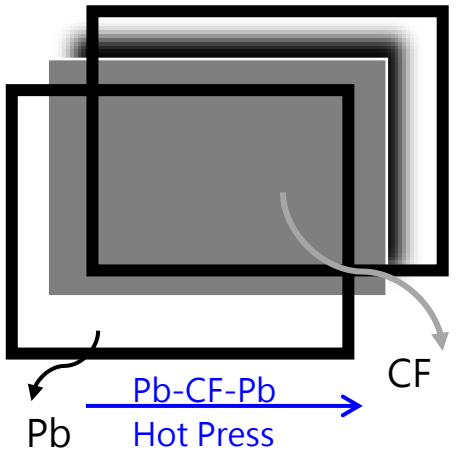
- **A continuous carbon material**
- **100% coverage of Pb on C**

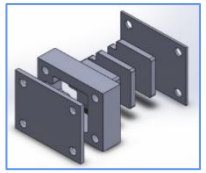


Monolithic and flexible Carbon Cloth



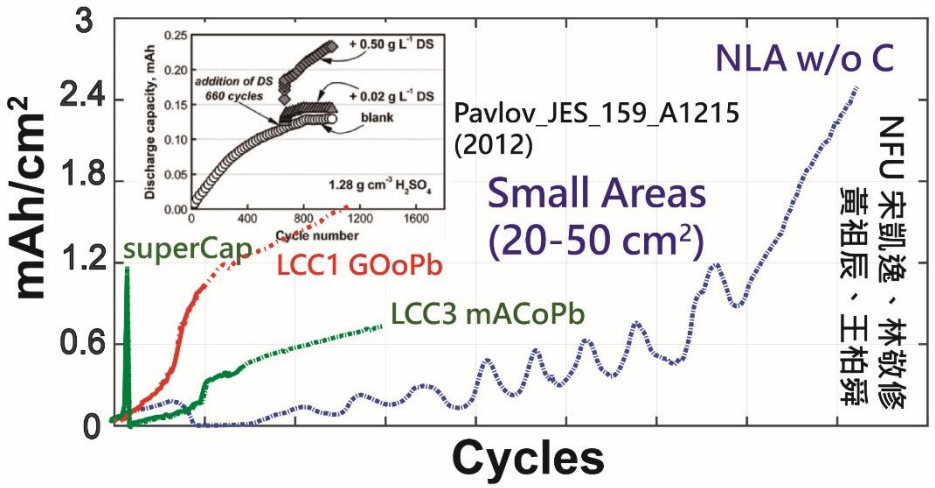
Carbon Fiber/Cloth SEM Morphology



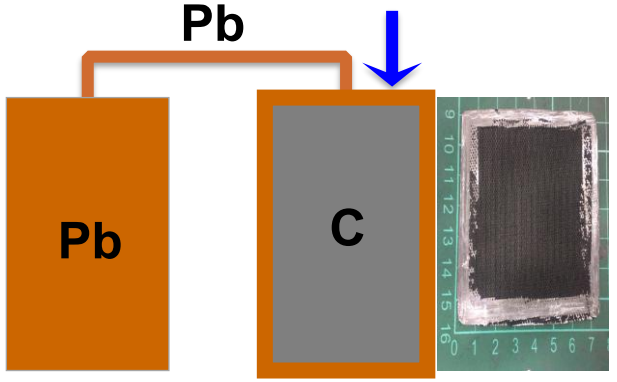


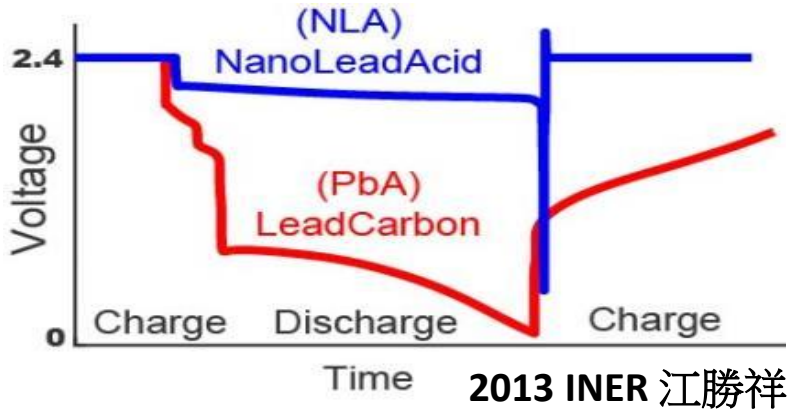
As is

NLA w/C and 3D Pore Structure (100% DoD)



Pb/C chemical interface





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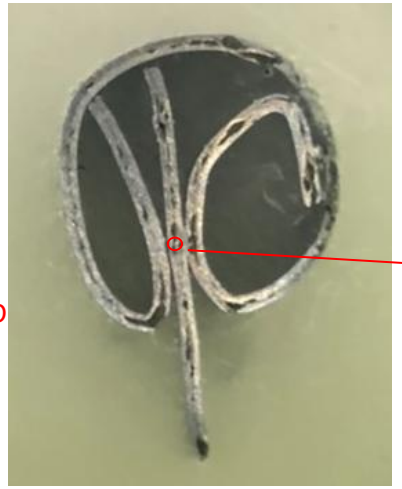
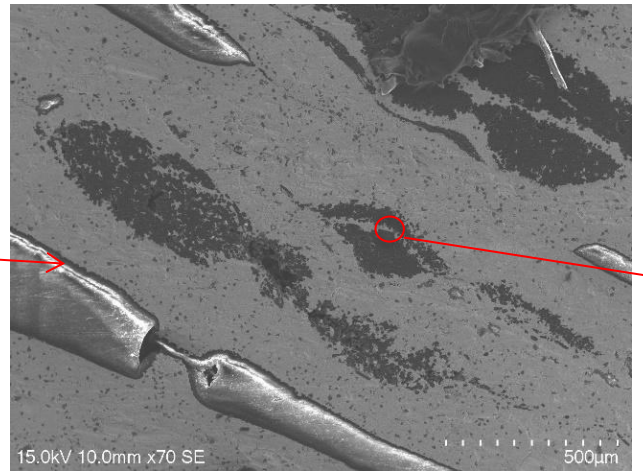
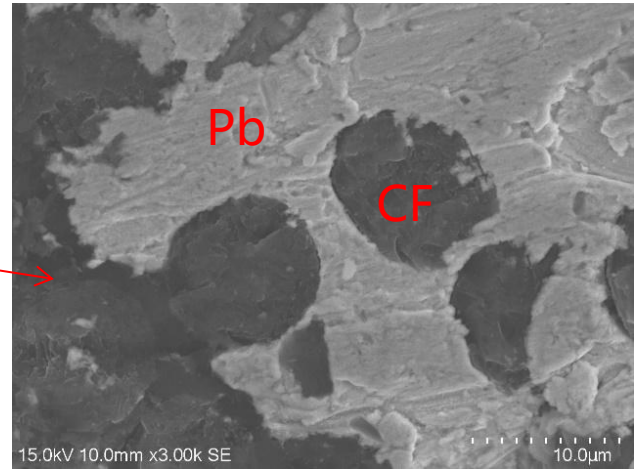
Lead Carbon Fiber Cloth Composite (LCF)

CF Electrode



Cross section



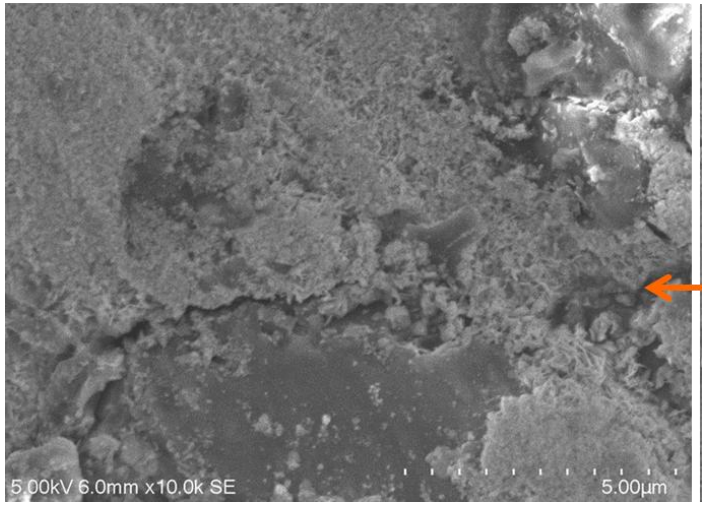


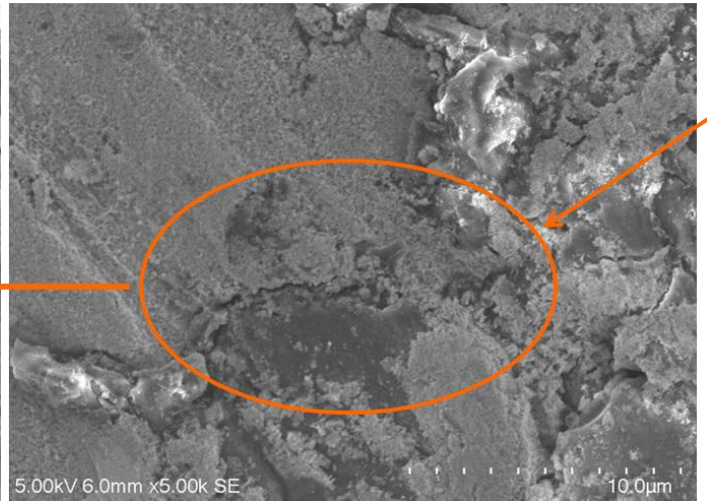
Low Temperature HOT Press

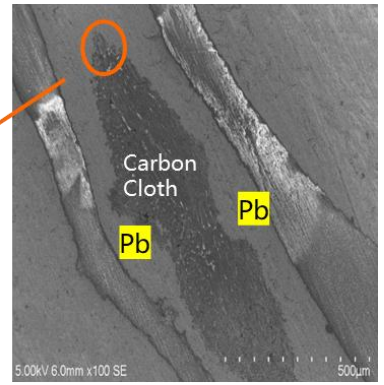
Yes!

600℃ → 400℃ → < 200℃

- ✓ **A continuous carbon material**
- ✓ **100% coverage of Pb on C**







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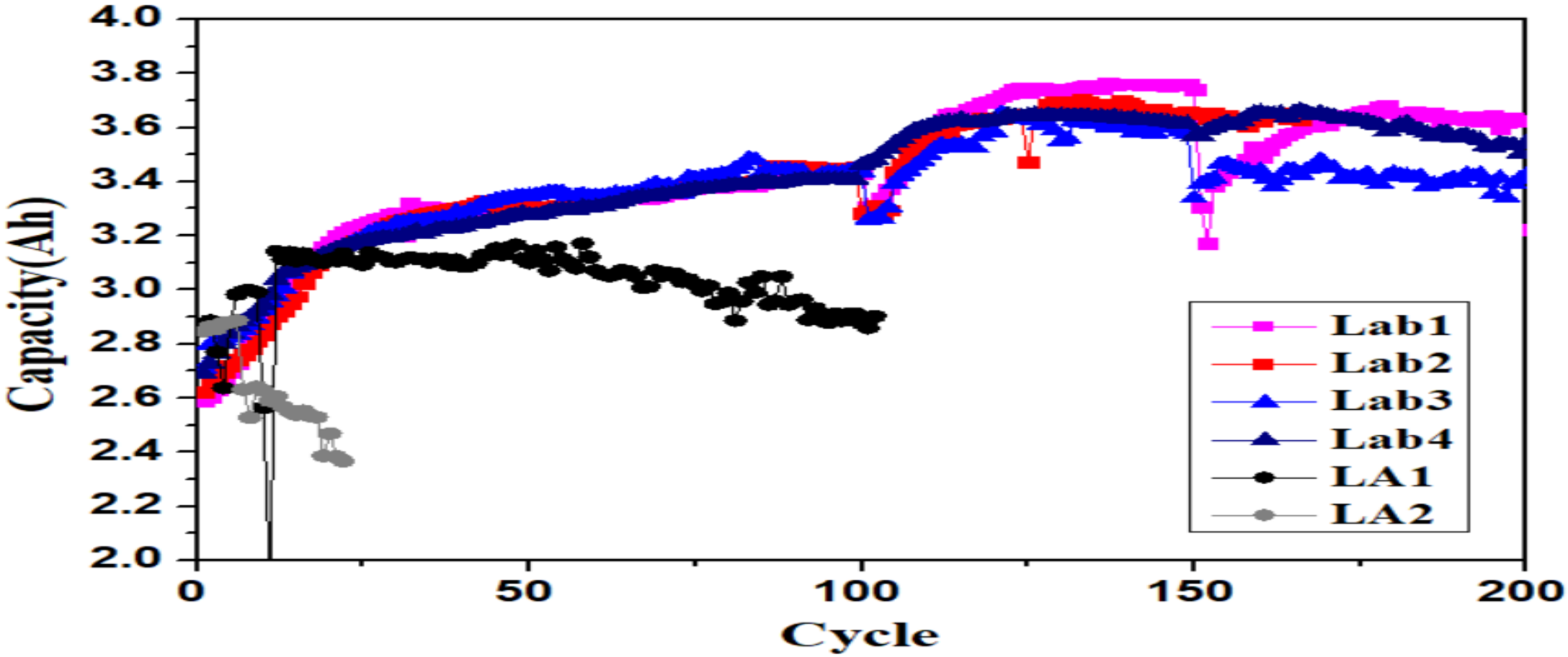
NanoMaterials Lab

Validation Test of LCF Insertion Effect on Lead_Acid Batteries

CC Discharge-Charge Process:
1C(4.8A) discharge to 1.8V
1C(4.8A) charge 1hr.

All 2V 4.8Ah batteries
Lab1, 2, and 3 : Lead-Acid Battery inserted LCF
LA1 and 2 : Lead-Acid Battery



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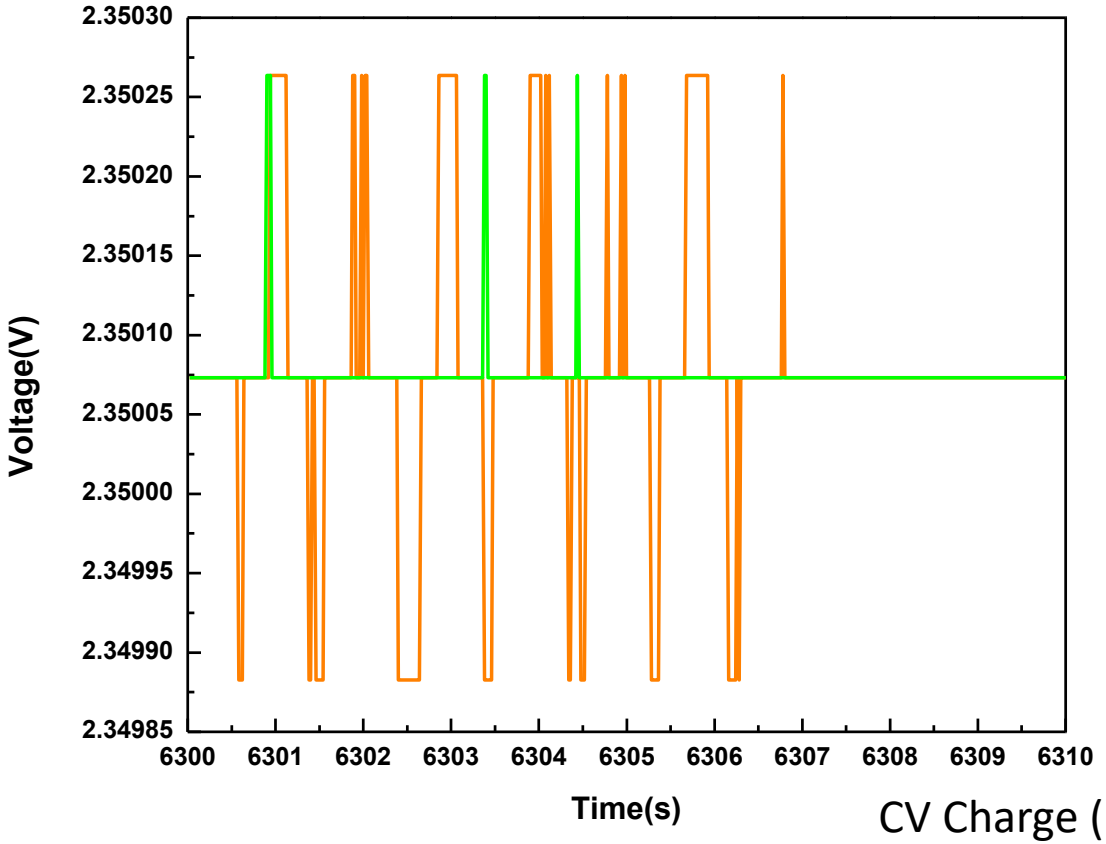
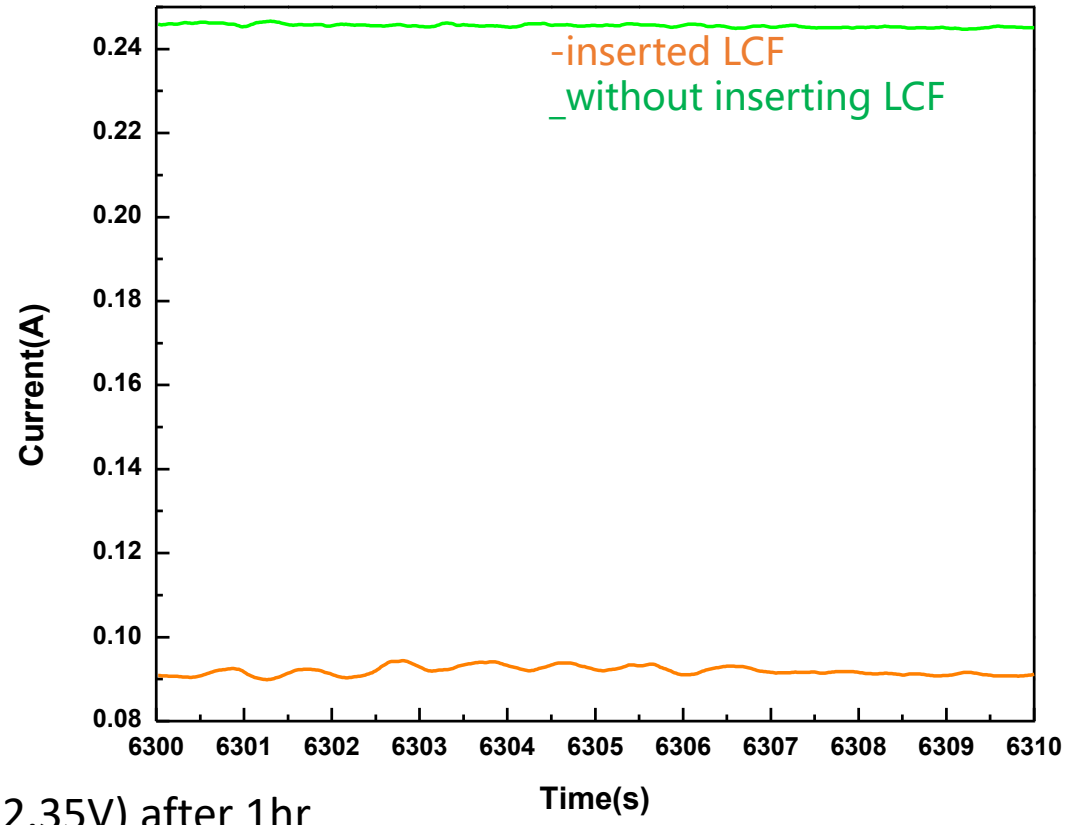
Battery inserted LCF vs Battery without inserting LCF

The charge voltage exhibits a pulsed profile, and the battery with inserted LCF shows a lower, wavy current at the final stage—indicating that the LCF functions like a capacitor to enhance charge acceptance.





CV Charge (2.35V) after 1hr

2V Cell_39*68 mm^2 electrode

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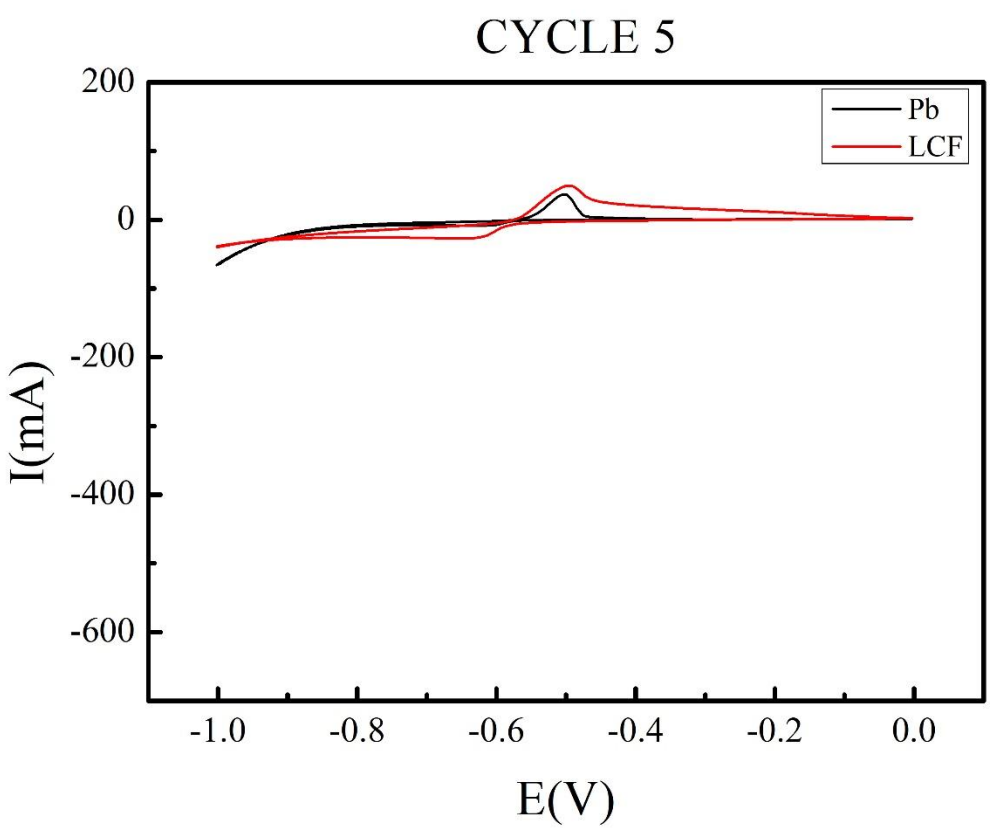
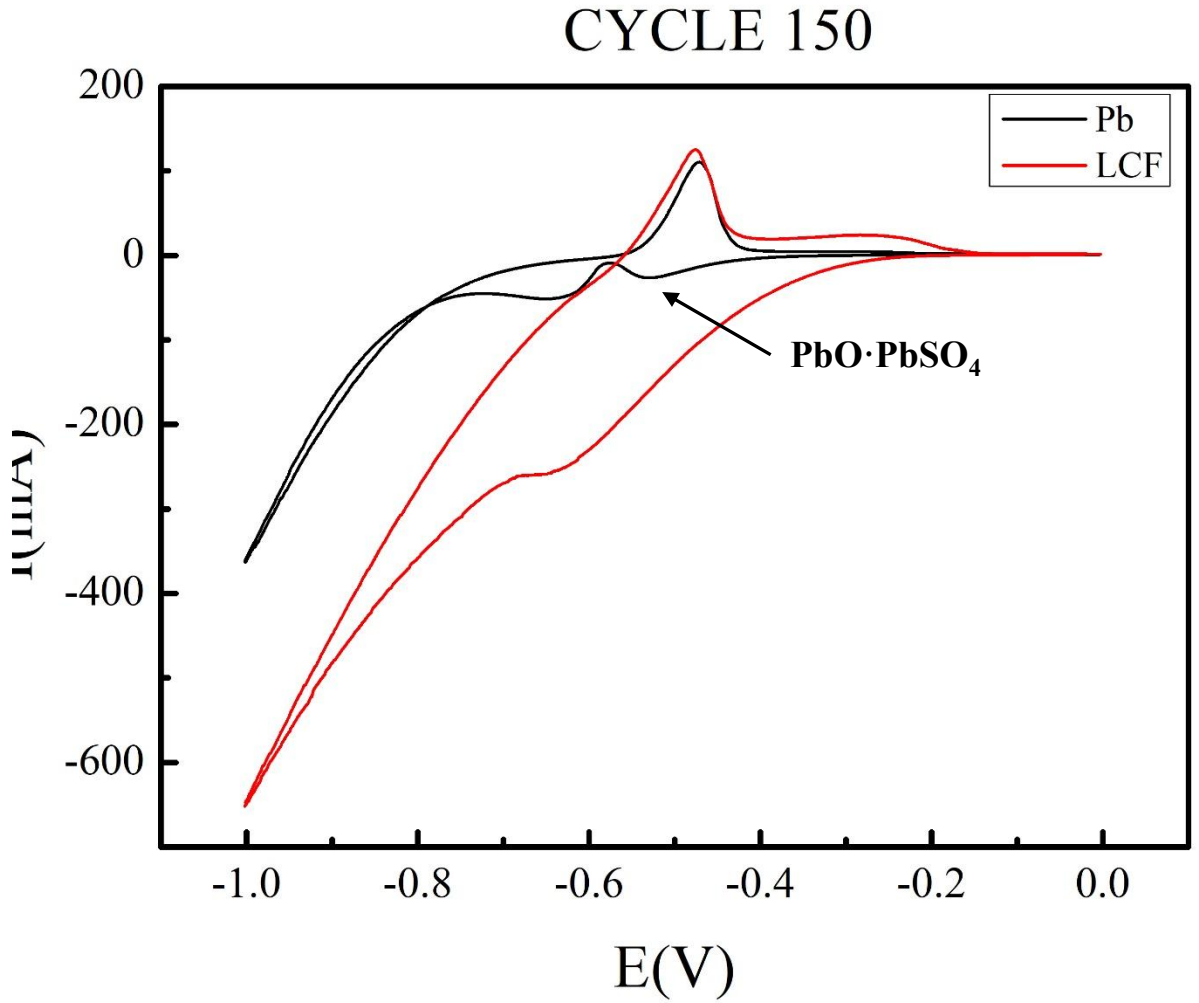
Cyclic Voltammetry of Pb vs. LCF





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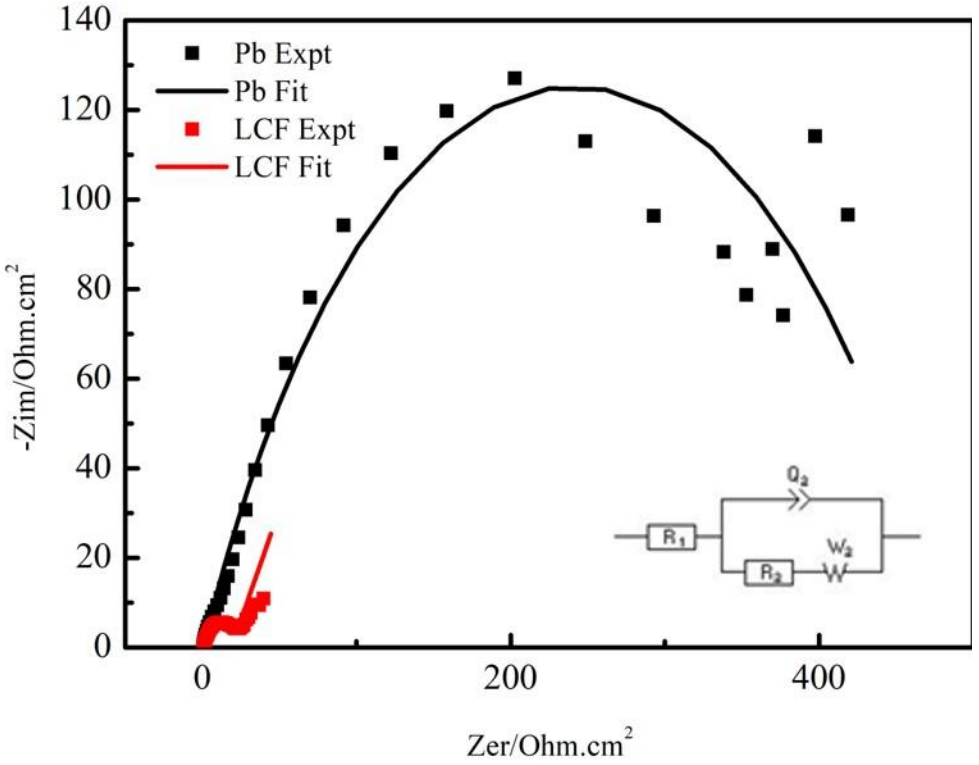
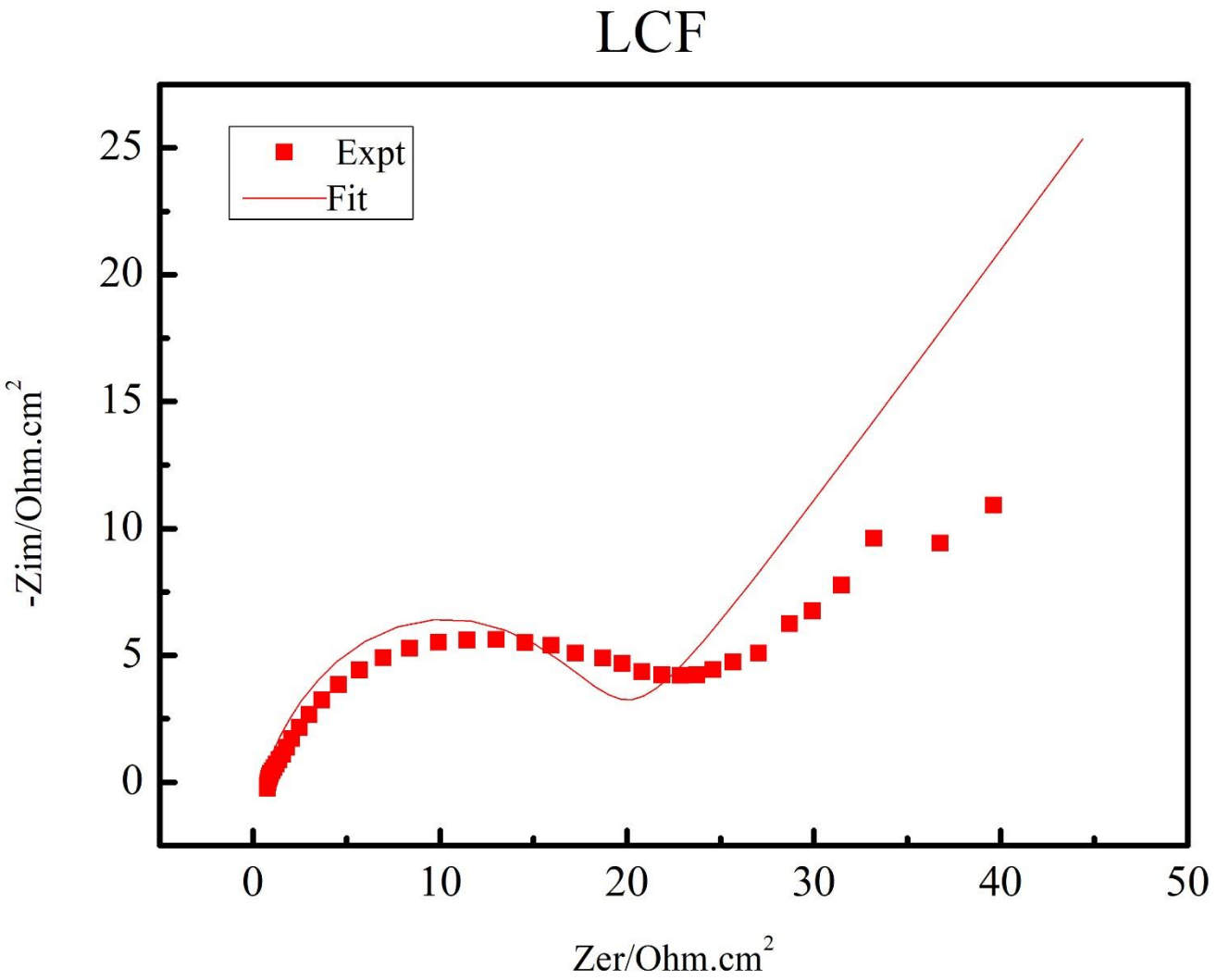
Electrochemical Impedance Spectroscopy of Pb vs. LCF

Sample	Rct (Ω)	Rs (Ω)
Pb	616.80	0.66
LCF	18.82	0.46





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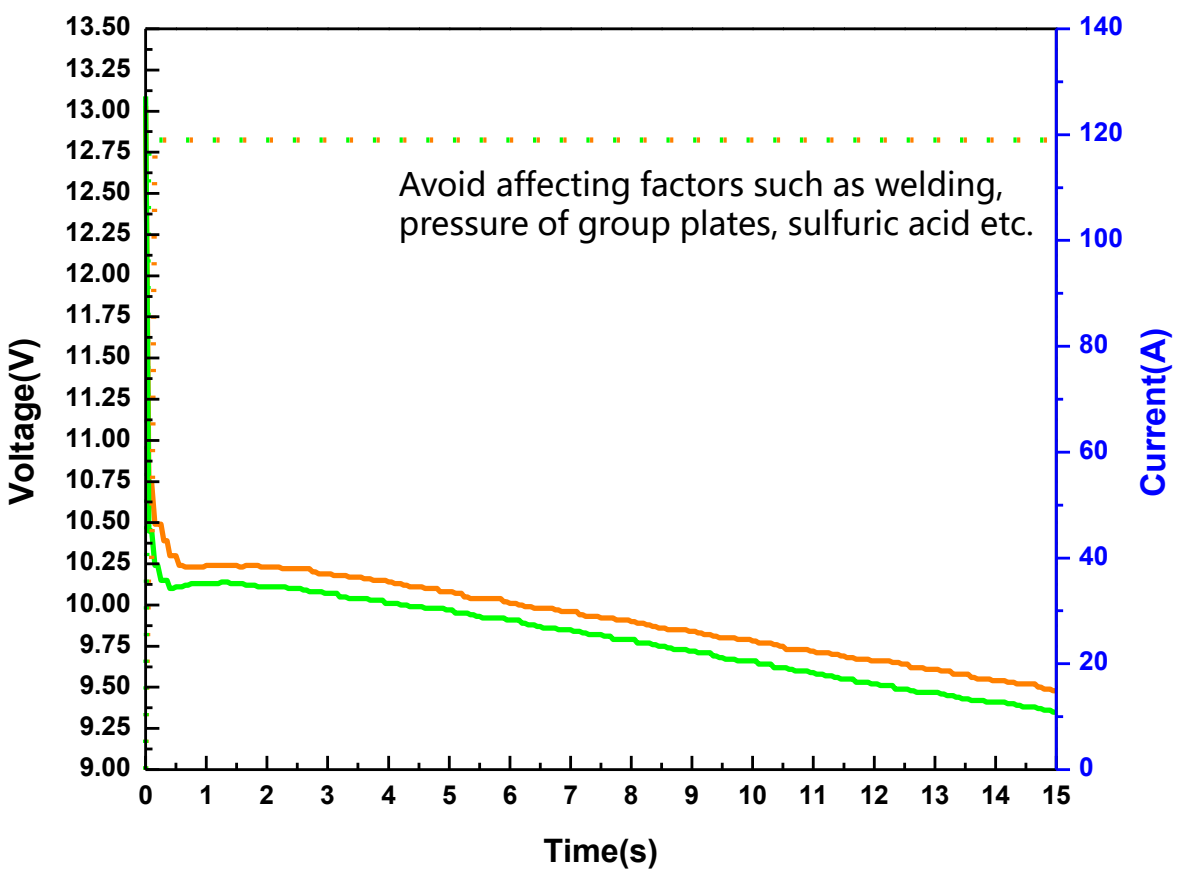
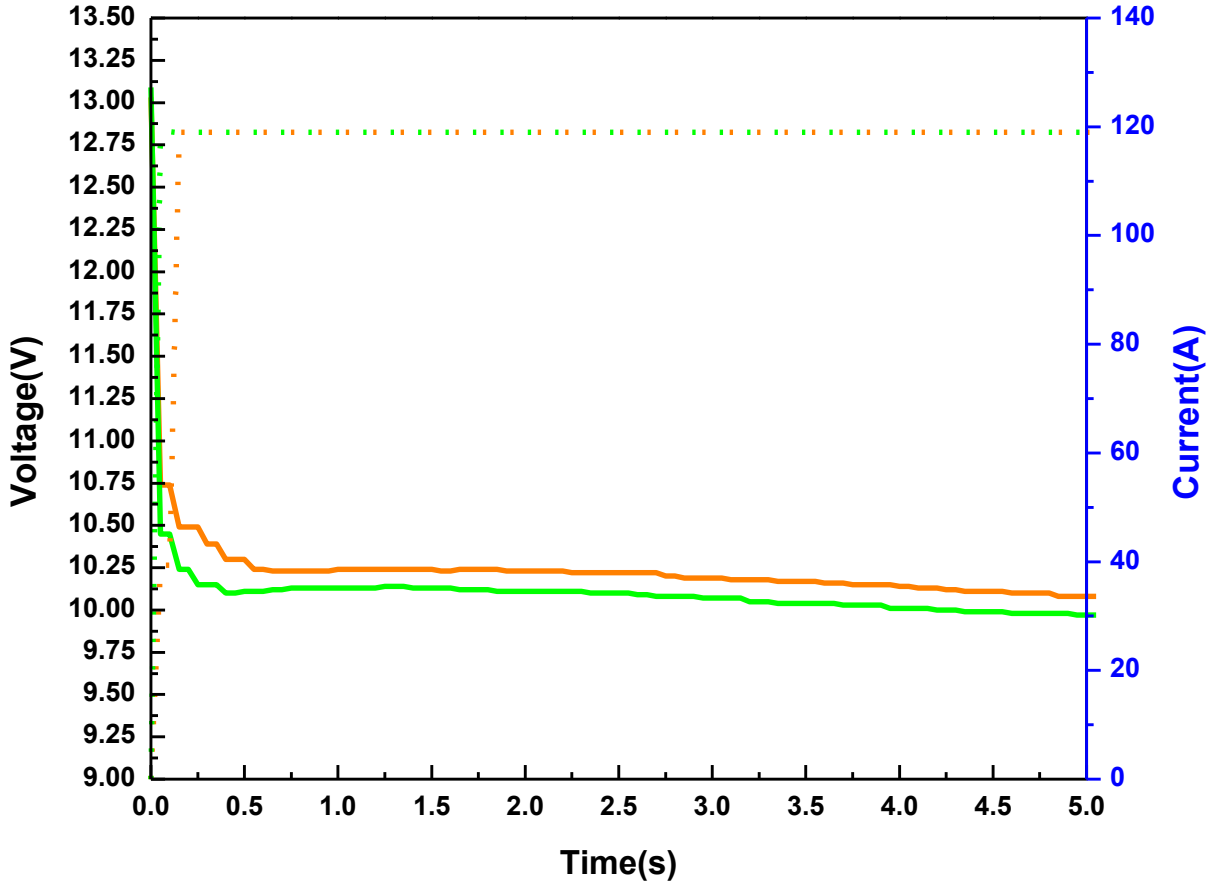
Battery inserted LCF (12V6AH) vs Battery without inserting LCF (12V7AH)

High Rate 119 A discharge 15sec

Battery inserted LCF 19.83C vs **Battery without inserting LCF 17C**





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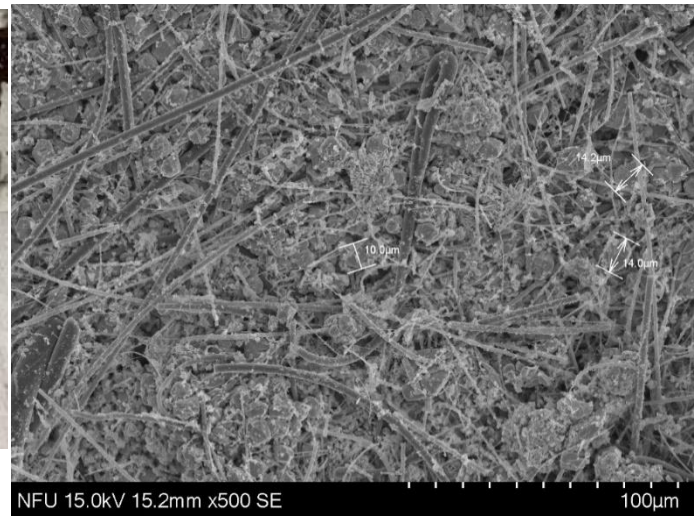
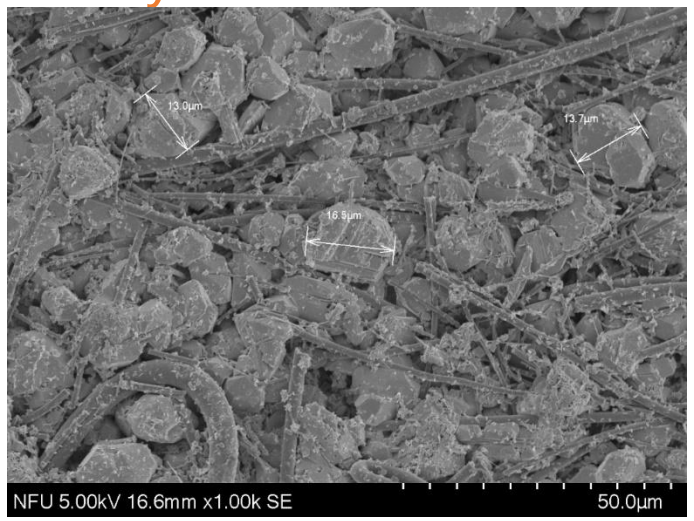
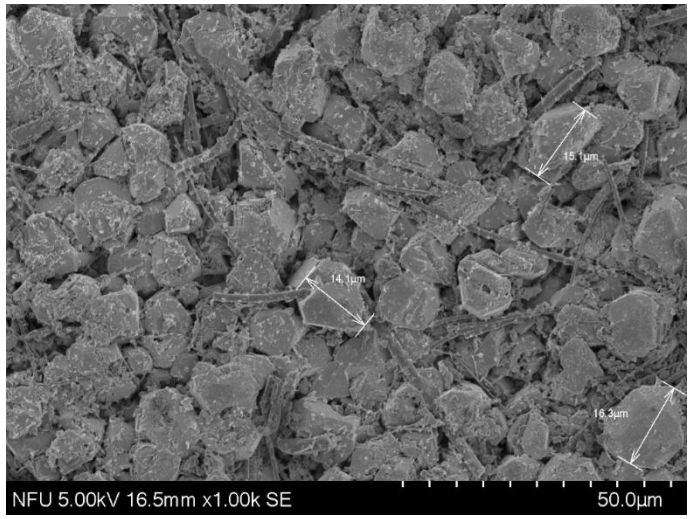
Negative Paste electrode of Failed Batteries after CP cycling

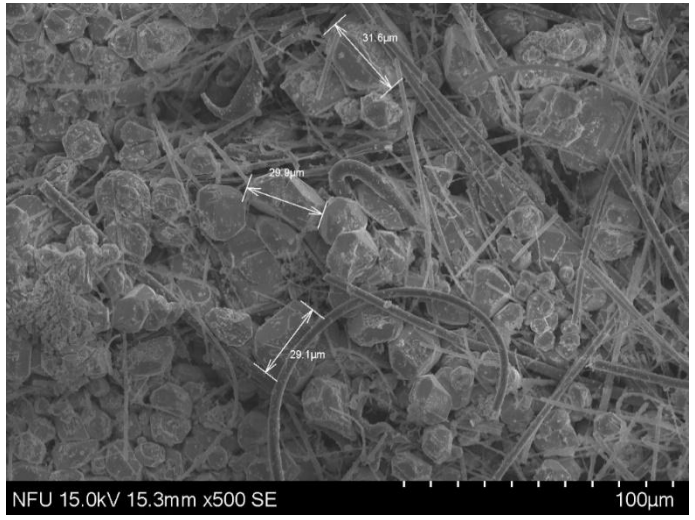
Battery inserted LCF

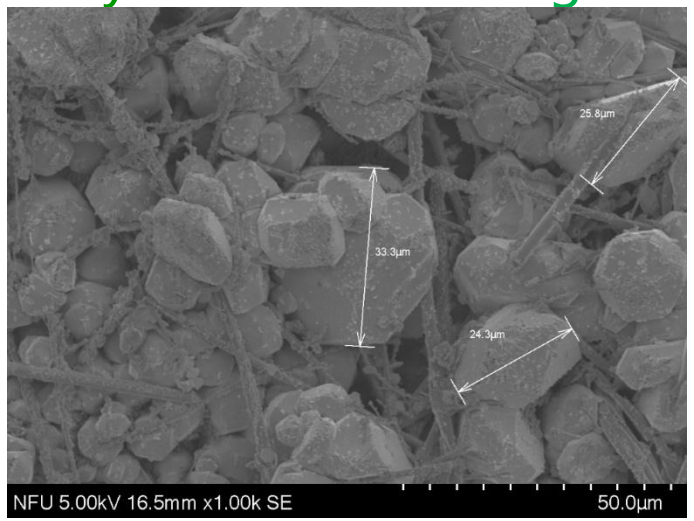


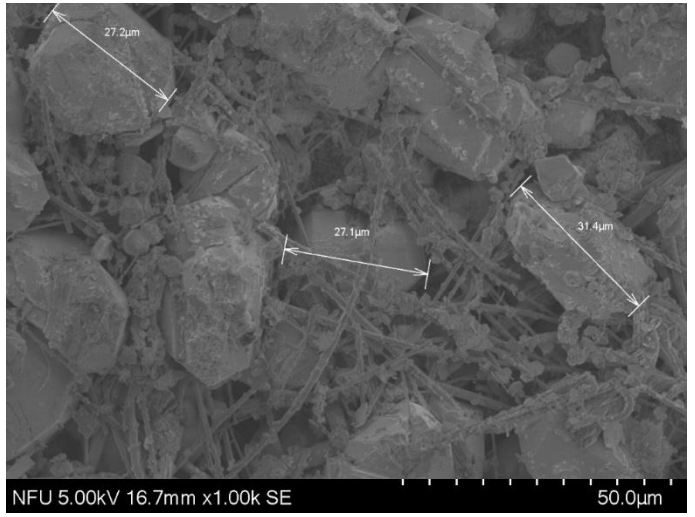




Battery without inserting LCF







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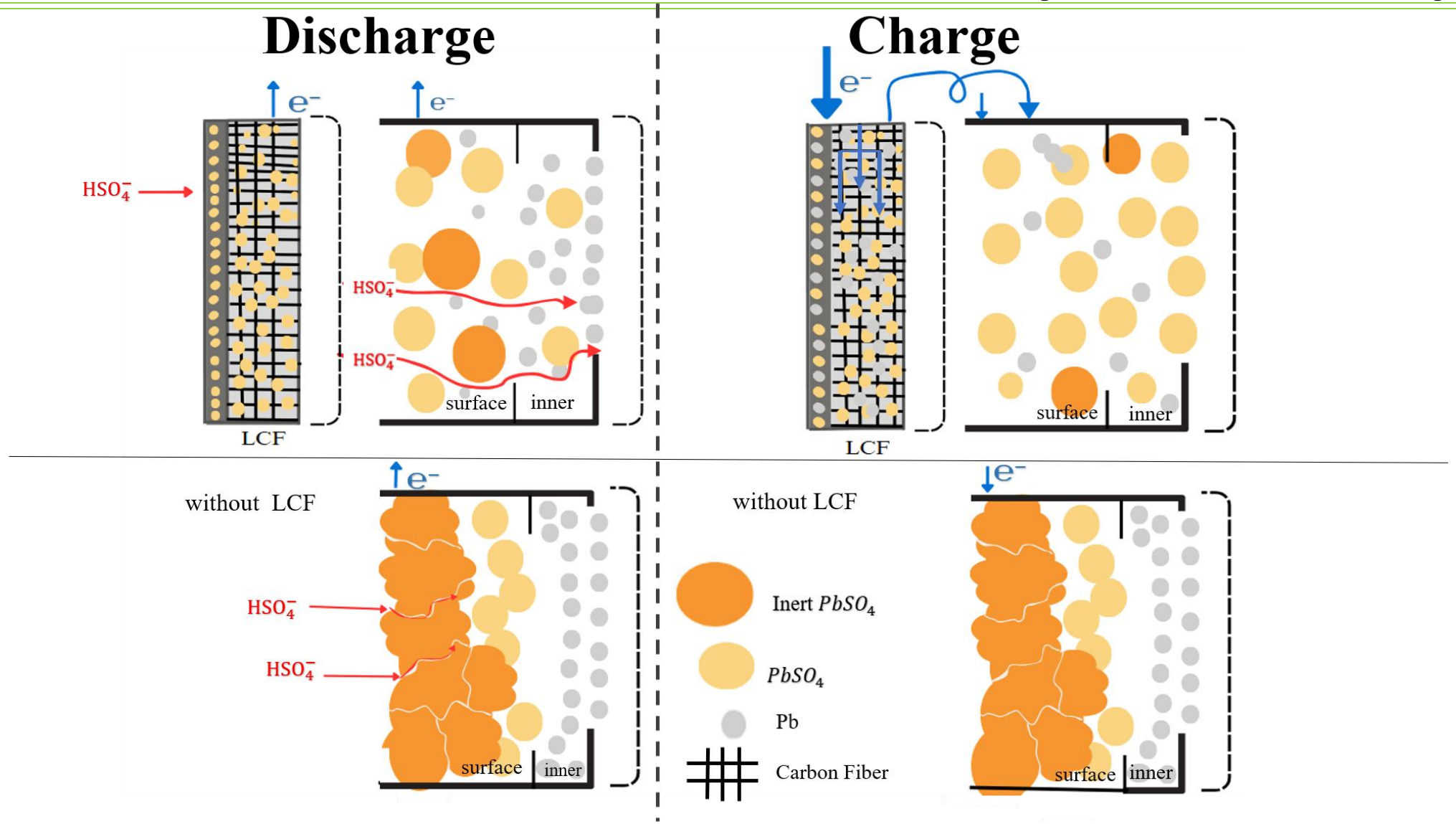
Proposed Mechanism of Lead–Acid Battery Enhanced by LCF



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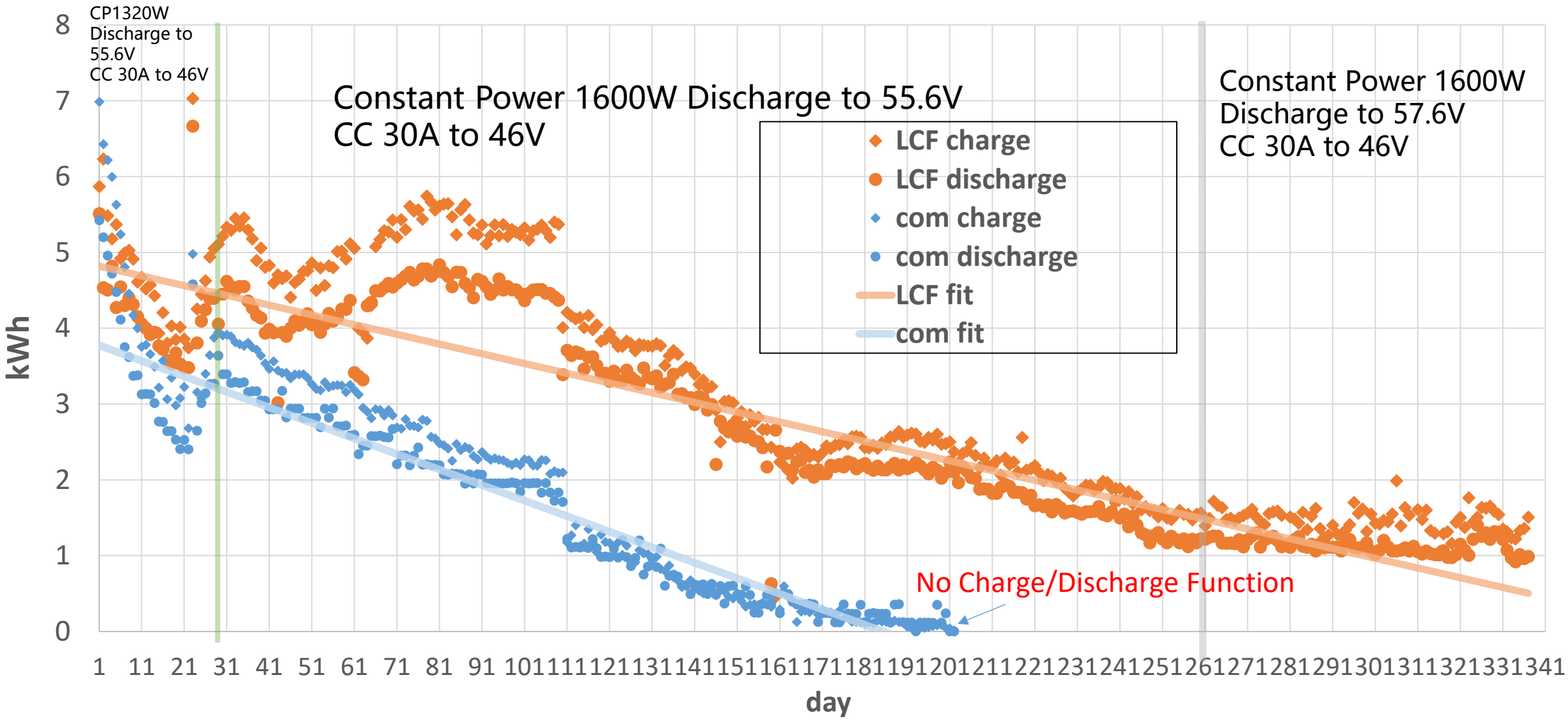
PV Energy Storage: Field Test vs. Commercial Battery Packs

Both Lab and Commercial 12V 65Ah cells were configured into 48V 195Ah battery packs, tested under identical Growatt PV equipment.

From August 2024 to July 2025



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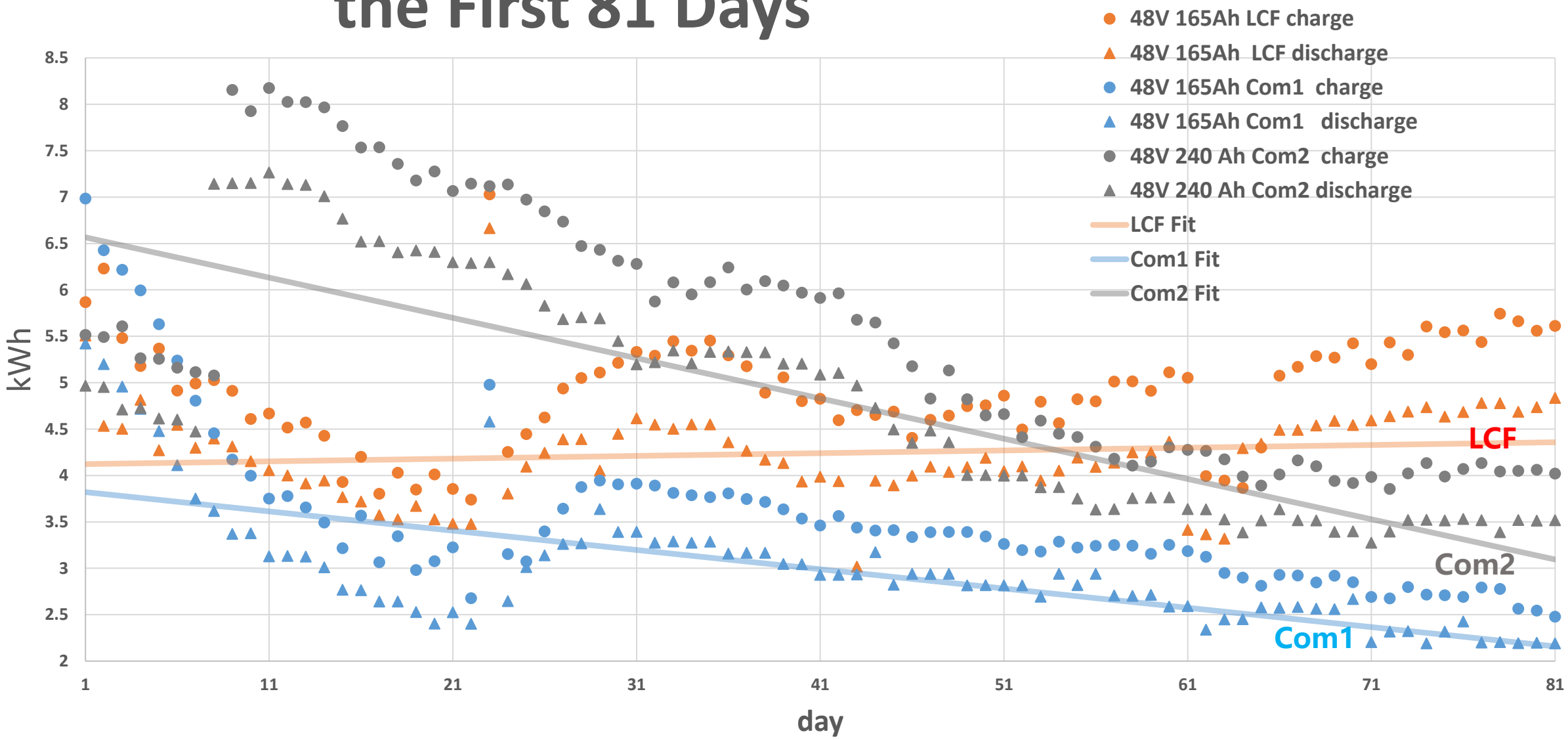
Performance of Three Battery Packs Over the First 81 Days



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Lab Battery(12V50AH) vs Commercial Battery (12V50AH)

田洋社區_鄧麗君出生地

來源:鄧麗君 何日君再來專輯封面貴族唱片出品

Birthplace of Teresa Teng Li-Chun

✓ LCF Battery(on work): 20231124 to Now

Commercial Battery (failed):2023/06/09-2023/11/24 <6 Months

- PV Charge to 28.8V /Discharge from 18:00~00:00
- No power_No sunshine due to rainy days or leaf shielding

LCF Battery Light Up Longyan Station

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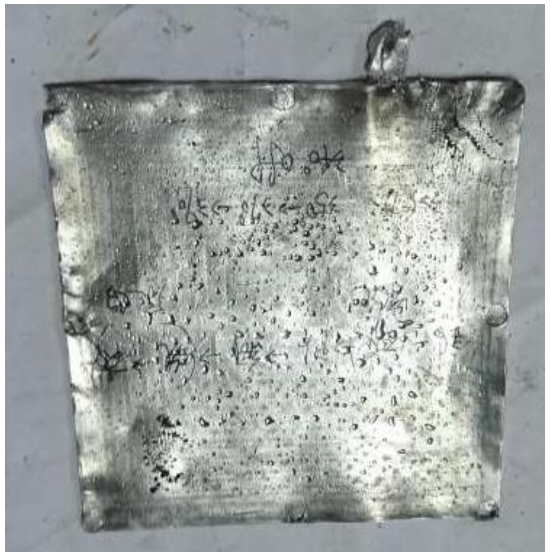
A Pure LCF Battery

Battery Consultant: Mr. Hank Wu

LCF electrodes act as electrodes to assemble a cell.



CF electrodes/plates

Tools / Battery parts

Plate Group

2V Battery

LCF 2V Battery_ +/- 6.6*3.9 cm

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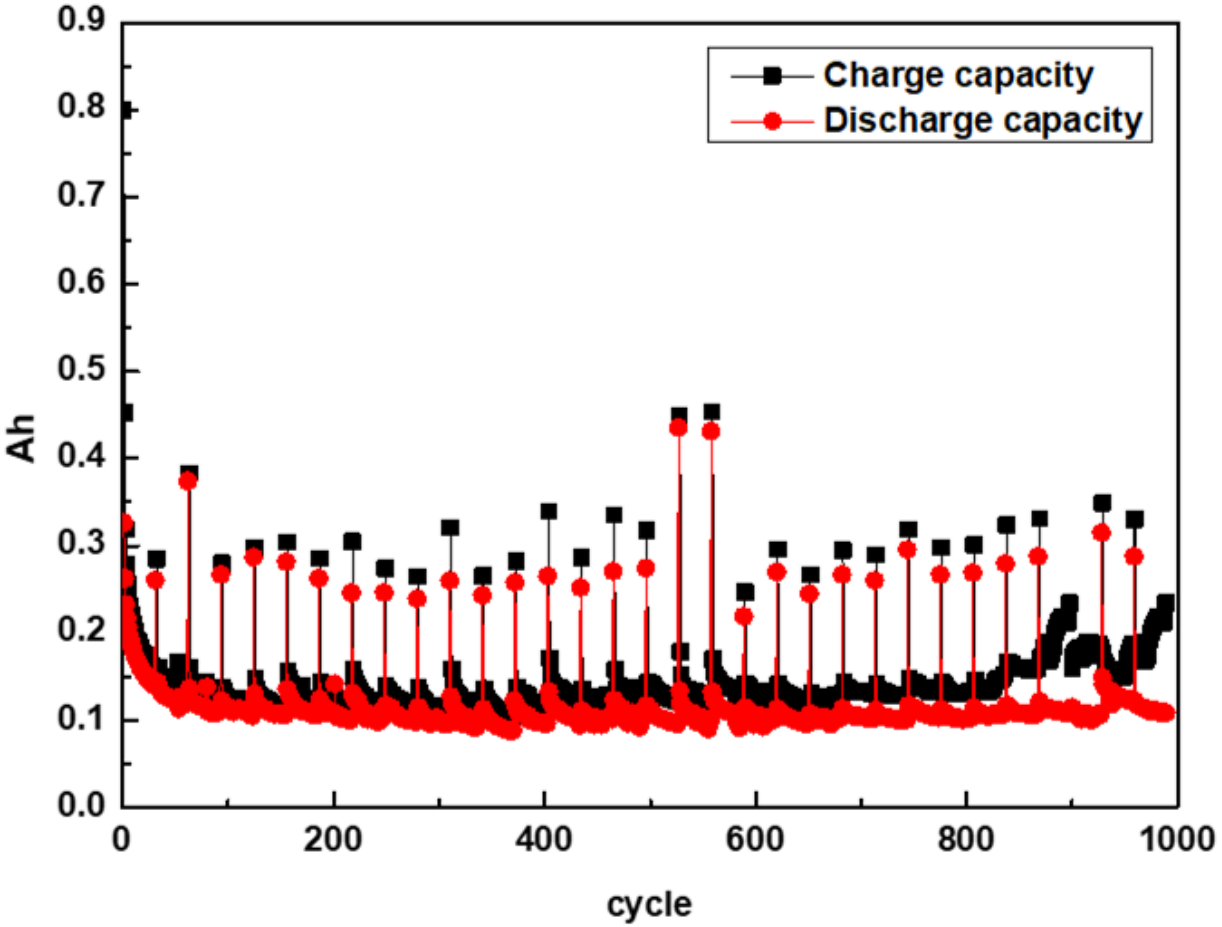
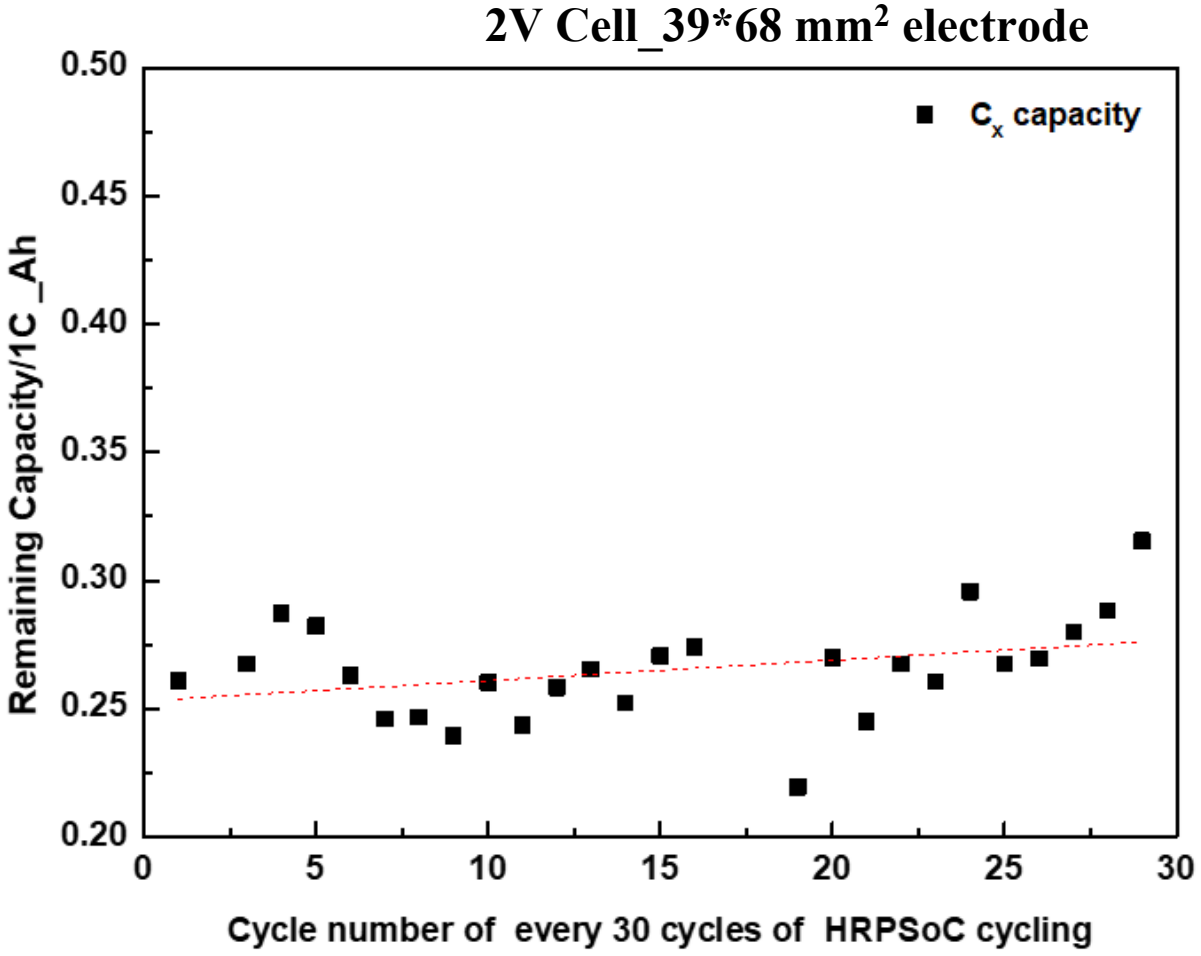
High-rate cycling test with 1C charge/3C discharge, then IEC61427

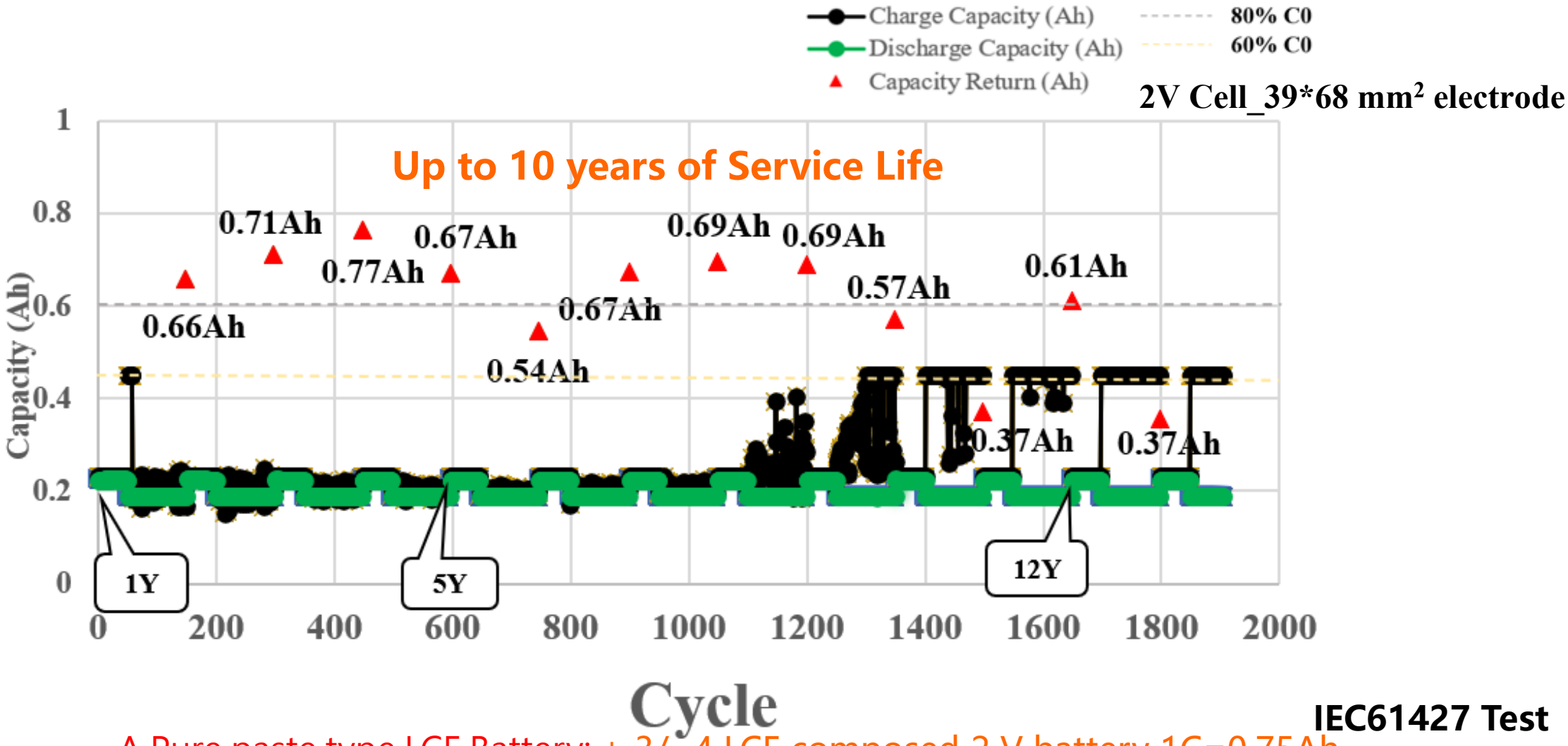




A Pure paste type LCF Battery: + 3/- 4 LCF composed 2 V battery 1C=0.75Ah

High-rate cycling test with 1C charge/3C discharge, then IEC61427

Service Life of *Pure* LCF Battery in PV System



IEC61427 Test

A Pure paste type LCF Battery: + 3/- 4 LCF composed 2 V battery 1C=0.75Ah

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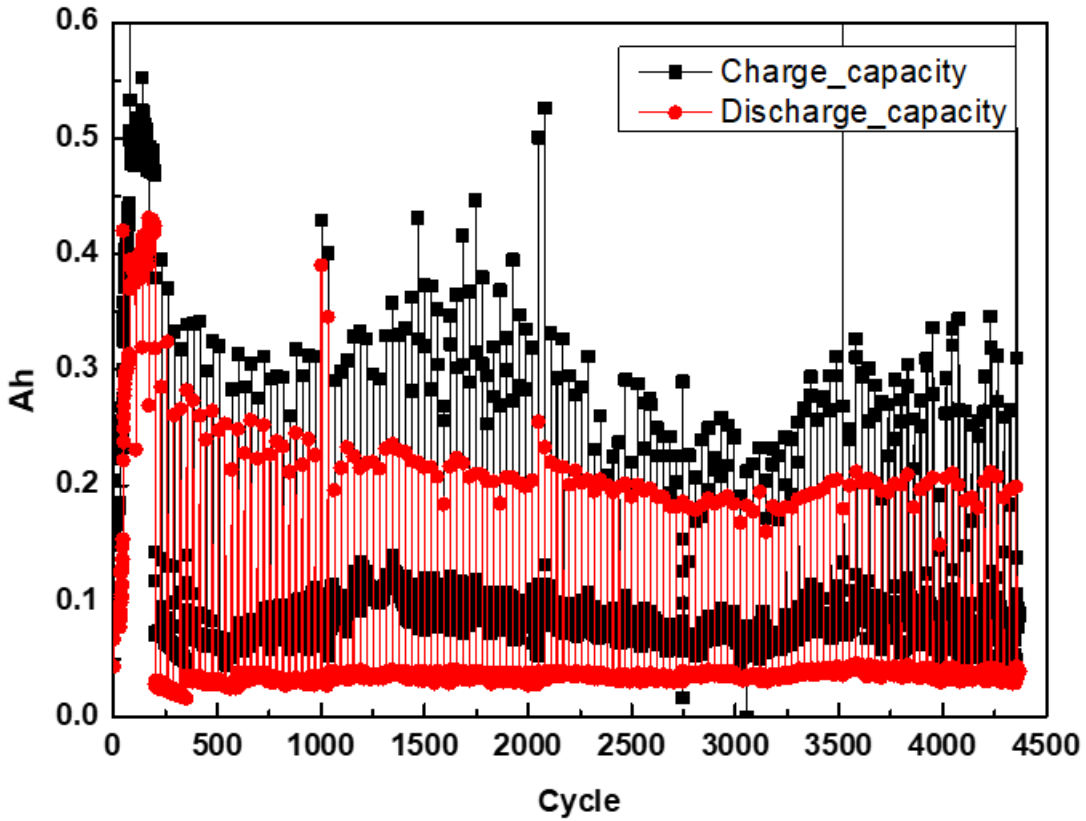
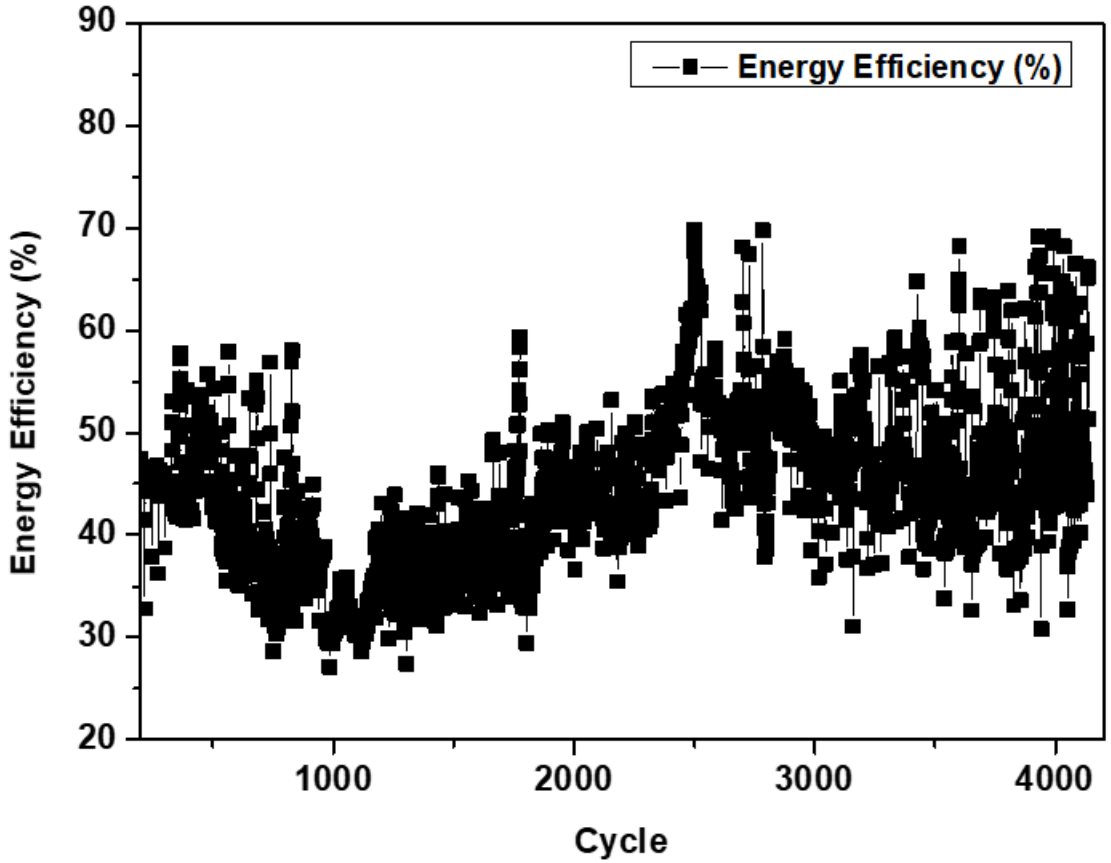
High-rate cycling test with 4C charge/10C discharge

A Pb/CF cloth/Pb composite as a highly efficient lead-carbon electrode exhibits notable charge acceptance and **long cycle life** for lead-acid batteries (LAB) during HRPSoC cycling





A Pure LCF Battery: + 2/- 3 LCF composed 2 V battery C10=0.3Ah

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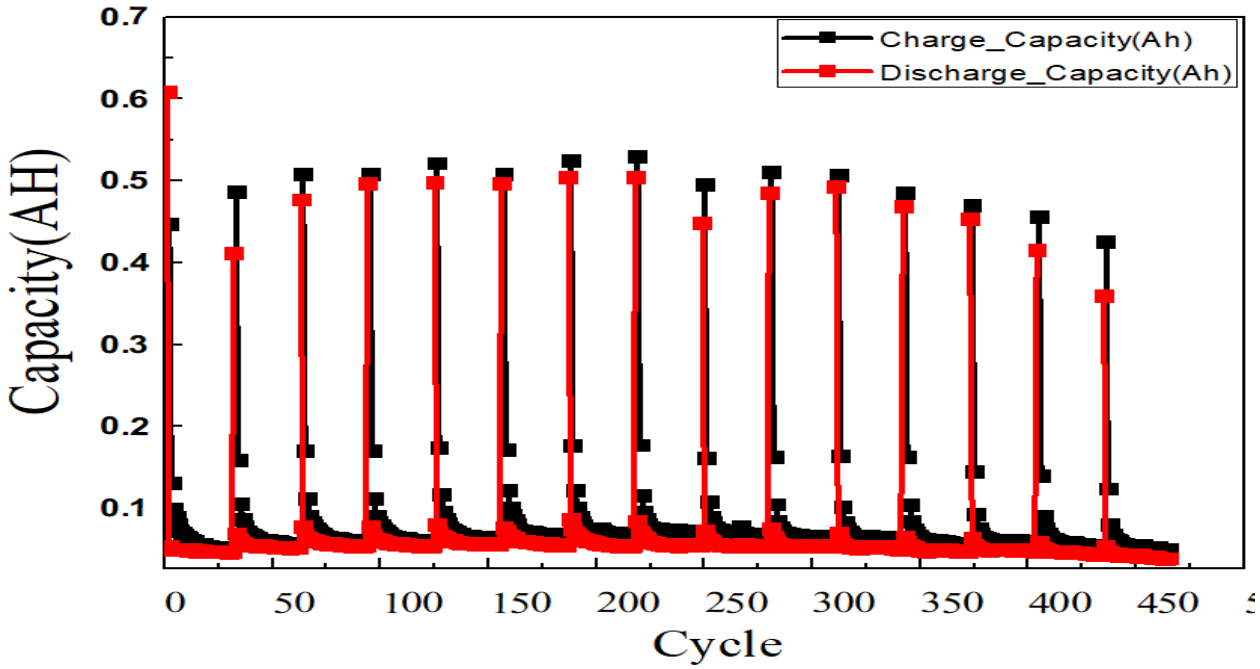
High-rate cycling test with 4C charge/10C discharge

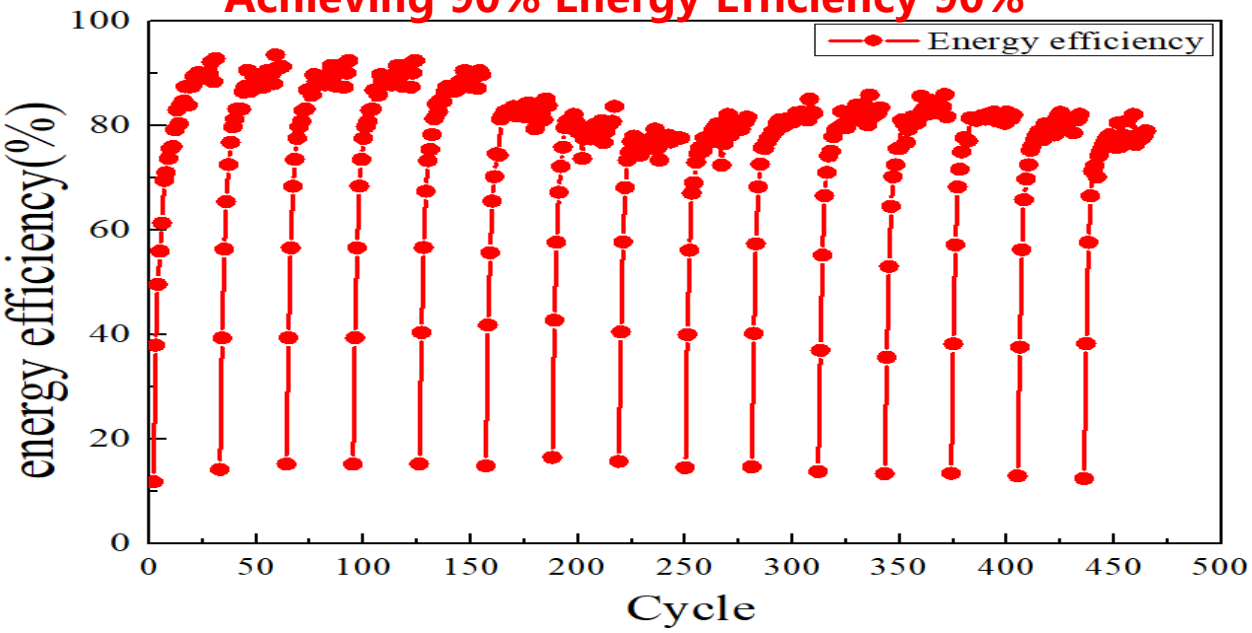
4C / 10C cycling test
2.8A CC Charge to V=2.35
Rest 30 min
2.35V CV Charge 2hr.
7A CC Discharge to V=1.5V

30 Cycles

Charge-Discharge Process for Capacity after Every 30 Cycles
0.07A CC Discharge to V=1.5V
0.28A CC Charge 6hr.
Rest 30 min
2.4V CV Charge 2hr.
0.1A CC Discharge to V=0.5V



Achieving 90% Energy Efficiency 90%



A Pure LCF Battery: + 4/- 5 LCF composed 2 V battery **C10=0.6 Ah → 2 Ah**

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NanoMaterials Lab

Conclusion

Lead-acid batteries are **safe, reliable**, and have been part of our lives for over **160 years**.

At our lab, we are committed to **improving the performance of lead-acid batteries** to support a more **sustainable and energy-efficient future**.

We sincerely invite you to **join our collaborative projects** and support the **continued development** of this promising battery technology.

Thank you for your Attention

Our lab continues to focus on bringing light to remote areas