BAK xEV Battery R&D and Industrialization

Jian Lin (林建）

CTO of CBAK

Contents

- BAK Introduction
  - Basic Information
  - Production and Detection Equipments
  - R&D Equipments
- xEV Battery Research
  - NMC Background
  - 18650 EV 2.1AH
  - 18650 EV 2.4AH
  - 18650 EV 3.1AH
  - 18650 EV 3.4AH
- xEV Battery Industrialization

China BAK

Company prospect: leading global manufacturer of Li-ion power battery

Applied area: EV, LEV, power tools, energy storage.

Tianjin BAK: Established in 2006

Registered capital:$99.99 million

Location: Beichen District, Tianjin, 520 acres

Production capability: 400MWH/Y

Dalian BAK: Established in 2014

Location: Huayuankou District, Dalian, 231acres

Production capability: 120MAH/Y

BAK Tianjin--xEV production base

BAK Tianjin blueprint

BAK History

★ BAK was founded in Shenzhen, China

★ Cooperating with A123, BAK achieved lithium iron phosphate battery industrialization first in the world

★ BAK International (Tianjin) was founded in Tianjin, China

BAK was given the status of "China's famous brands"

★ BAK International went into production

★ Signed a contract of high power battery supply with the First Automobile Group

★ Bulk supply to chery and other customers

2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2014

★ Production capability was increased to 1 million cells/day from 2002 to 2005

★ Entered NASDAQ. Code: CBAK

★ Shenzhen BAK started to produce Li ion batteries for Laptop

★ BAK carried out 863 EV Project of Ministry of Science and Technology

★ Automobile Research Institute was established in Beijing

★ Dalian BAK Power battery Co. Ltd was established

Main Production Equipments

Mixing

Coatting

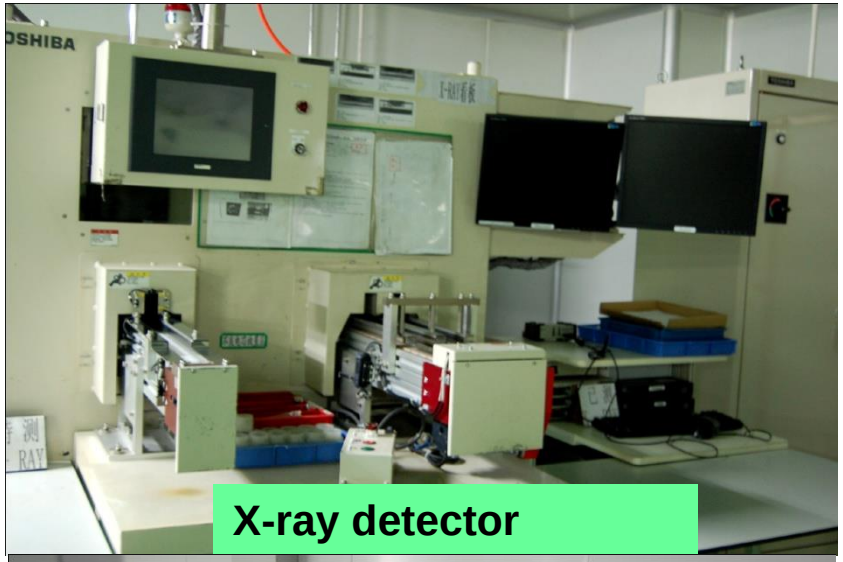
Rolling

slitting

winding

Assembling

Testing Equipments



X-ray detector

EV testing system

Vehicle module detection cabinet

Vehicle module detection

R&D Equipments

- SEM-EDS

- ARC

- BET

- FTIR

- PSA

- XRD

- DSC

- ICP

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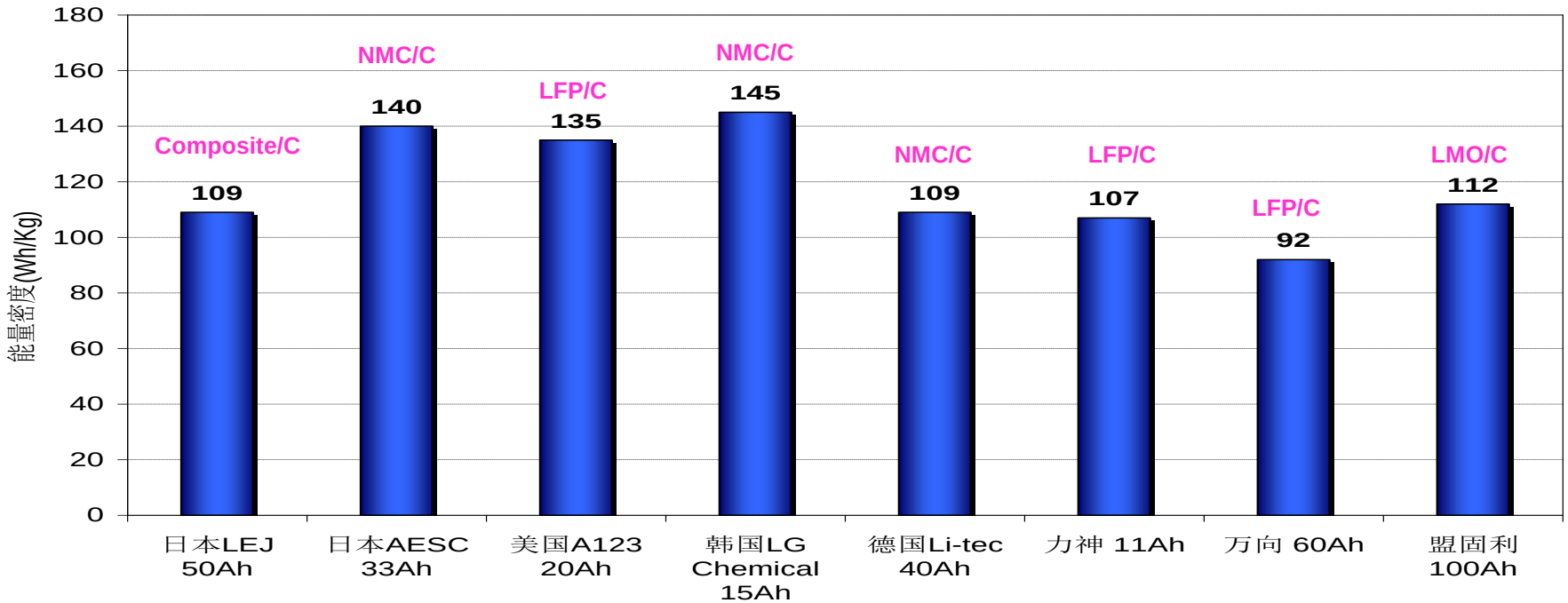
Why NMC- Energy Density（Range）

《Industry development plan of energy saving and new energy vehicles》published by State Council of China on Apr. 18, 2012.：

By 2015, specific energy density of EV battery module should be over 150Wh/kg.



- At present, ED of EV applying LFP cells is lower than 140Wh/kg.
- **ED of BAK Gen.1 EV 18650-2.0Ah is over 160Wh/kg.**

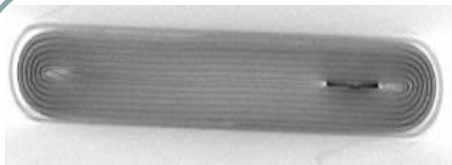
Why 18650-Energy Density（Range）

	Cathode	Cap. (Ah)	Specific ED (Wh/kg)	Volume ED (Wh/l)		Cathode	Cap.(Ah)	Specific ED (Wh/kg)	Volume ED (Wh/l)
18650	NMC	2.0	164	436	**Prismatic large cell(PHEV2,2614891)**	NMC	25	120	257
		2.1	175	457			28	143	296
		2.4	184	523			34	160	349
	NCA/NMC	3.1	254	675					

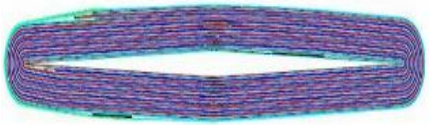
Fresh cell

Fully charged or after cycle

Circular structure is stable, pressure of each direction is even , could well accept electrodes swelling.



Fresh cell



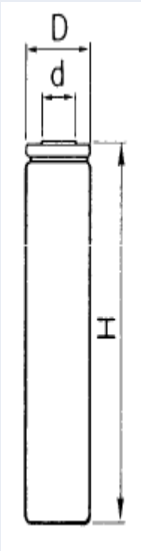
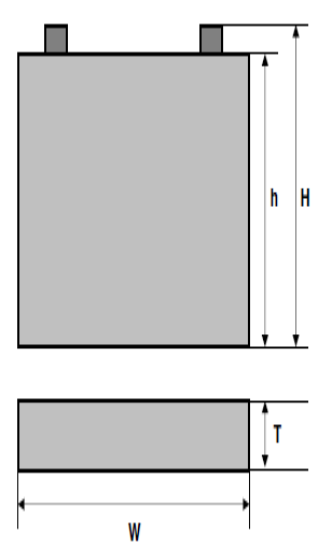
Full charge or after cycle

Mechanical strength along the thickness direction is weak; clamp and high pressure is used in module formation.

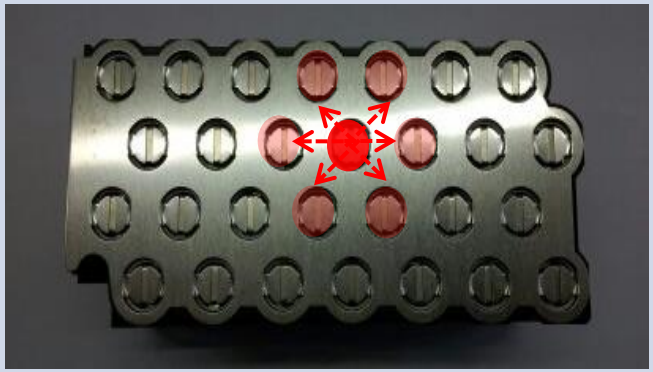
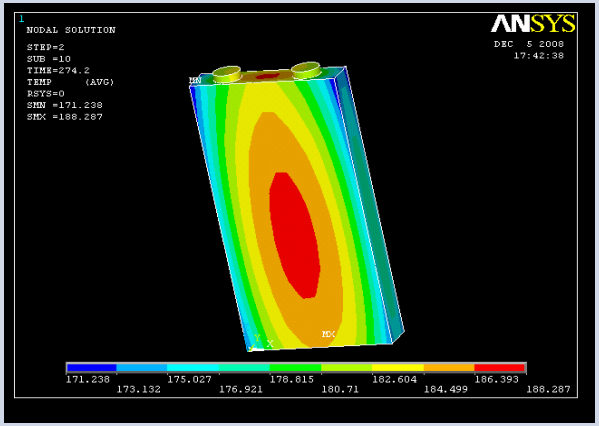
Why 18650 Safe- Low Unit Energy

"Intrinsic" Safety : Device safety is based on energy amount contained. Even the basic unit has safety issue, it will not cause chain reaction which may result in higher level damage issues.

Energy Low Enough- Fail-Safe

18650	Capacity (Ah)	Energy (Wh)	Specific ED (Wh/kg)	Energy per area (Wh/cm²)	PHEV2	Cap. (Ah)	Energy (Wh)	Specific ED (Wh/kg)	Energy per area (Wh/cm²)
	2.0	**7.2**	**164**	**0.1669**		25	90	120	0.2588
	2.1	7.56	175	0.1752		28	100.8	143	0.2898
	2.4	8.64	184	0.2003		34	**122.4**	**160**	**0.3519**
18.5*65 mm	3.1	11.16	254	0.2587	**26.5*148*91mm**				

Why 18650 Safe-Simulation of Thermal Runaway

18650 2.0Ah 1S28P （56Ah） Module	Prismatic >50Ah Cell
If single cell thermal runaway :  18650 cell has low single cell energy, good heat conducting of steel can, and heat diffusion path is long between cells in module (isolated space designed). **Obtain enough escape and emergency rescue time.**	If single cell thermal runaway :  Cell with too large energy has poor internal heat diffusion, **results in serious consequence in short time.**
Real operation result of a mis-welding module (some cells were anti-welded). **Only mis-welding cell failed, nearby cell is perfect!**	Over charge test of 20Ah prismatic cell **Large deformation may cause chain-reaction in module.**

xEV Battery Products

Current	Voltage（V）	IMP (mΩ)	Cap. (Ah)	Weight（g）	Pulse Discharge (A /2s)	Energy Density Wh/kg	Power Density W/kg
26650HP	3.2	<12	2.3	≤78	70	94	2153.8
26650MP	3.2	<20	2.9	≤78	40	118.9	1230.7
36800MP	3.2	<10	6.5	≤178	80	116.85	1078.6
26700HE	3.6	<50	5.0	≤98	10	183.67	326.5
H18650CB	3.6	<50	2.0	≤45	12	164	853
H18650CFL	3.6	<50	2.1	≤45	12	175	850
H18650CIL	3.6	<50	2.4	≤46	15	184	843

1. 26650HP:HEV application
2. 26650MP/36800MP:EV/PHEV application
3. H18650CB/CFL/CIL:EV application

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18650 EV 2.1AH General Performance

Test Item	Test Condition	Criteria	Test standard	Assessment
5.4.1. Discharge rate capabilities	25℃,Charge at 0.5C Discharge at :0.2C/0.5C/1C/2C	0.5C/0.2C ≥ 95% 1.0C/0.2C≥90% 2.0C/0.2C≥85%	+0.5C,4.2V,21mA/-0.5C,3.0V	OK
5.4.2. Cycle life	Charge at 0.6C, discharge at 0.6C, 2000 cycles, Room temp.	2000th Residual capacity/ Original discharge capacity≥70%.	BAK H18650CFL spec.	OK
5.4.3. High-Low temperature discharge performance	Charge :0.5C at RT Discharge :0.5C, at -10℃，0℃，25℃，60℃，	-10℃/25℃≥60% 0℃/25℃≥75% 60℃/25℃. ≥100%	BAK H18650CFL spec.	OK
5.5.4. Storage Performance	Fully charged, stored at 25℃ for 28 days.	Residual capacity / original capacity≥90%. Recovery capacity / original capacity≥95%	BAK H18650CFL spec.	OK

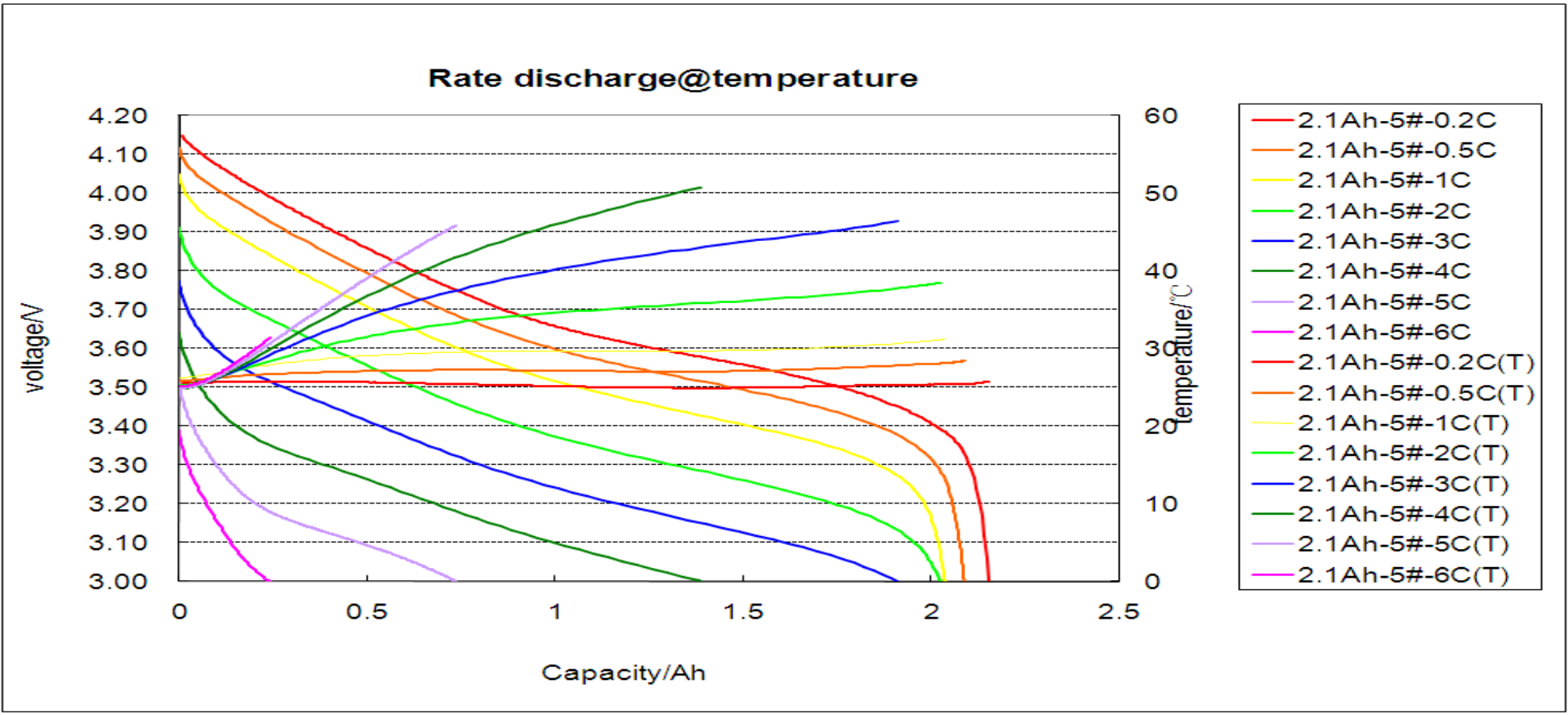
We use stable NMC111 and AG plus ceramic coating on anode to ensure long cycle life and safety.

18650 EV 2.1AH Safety Performance

Test Item	Test Condition	Test Standard	Assessment
5.5.1. Vibration	Fully charged, Simple harmonic, 0.8mm, 10~55Hz, 1Hz/min, 90~100min 1 cycles, 2 mutually perpendicular directions	UL1642	OK
5.6.1.Overcharge Test	Fully discharged, 12V ,1C for 1.5hrs	UL1642	OK
5.6.2.130℃ Oven Test	Fully charged cell is risen from RT with a rate of 5℃/min, remain for 1 hour @ 130℃	UL1642	OK
5.6.3.Over discharge Test	Fully charged, discharged by 0.2C current for 12 hours	UL1642	OK
5.6.4. Crush Test	Fully charged cell，apply pressure of 13KN，32mm diameter piston.	UL1642	OK
5.6.5 Short Circuit Test	25℃&60℃, fully charged cell, to short the cell with a copper wire of less than 50mΩ.	UL1642	OK
5.6.6. Incineration test	Fully charged cell, test according to UL1642.	UL1642	OK
5.6.7.Impact test	Fully charged, 7.9mm diameter bar. 9.1kg weight,610mm	UL1642	OK
5.6.8 Drop test	Drop ,1.1m height on hard board, with three directions	BAK	OK

Level	C0	C1	C2	C3	C4	C5	C6
Criteria	No change	Leakage	Smoke, <200 ℃	Smoke, >200 ℃	Fire	Explosion	Explosion where battery penetrates wire screen

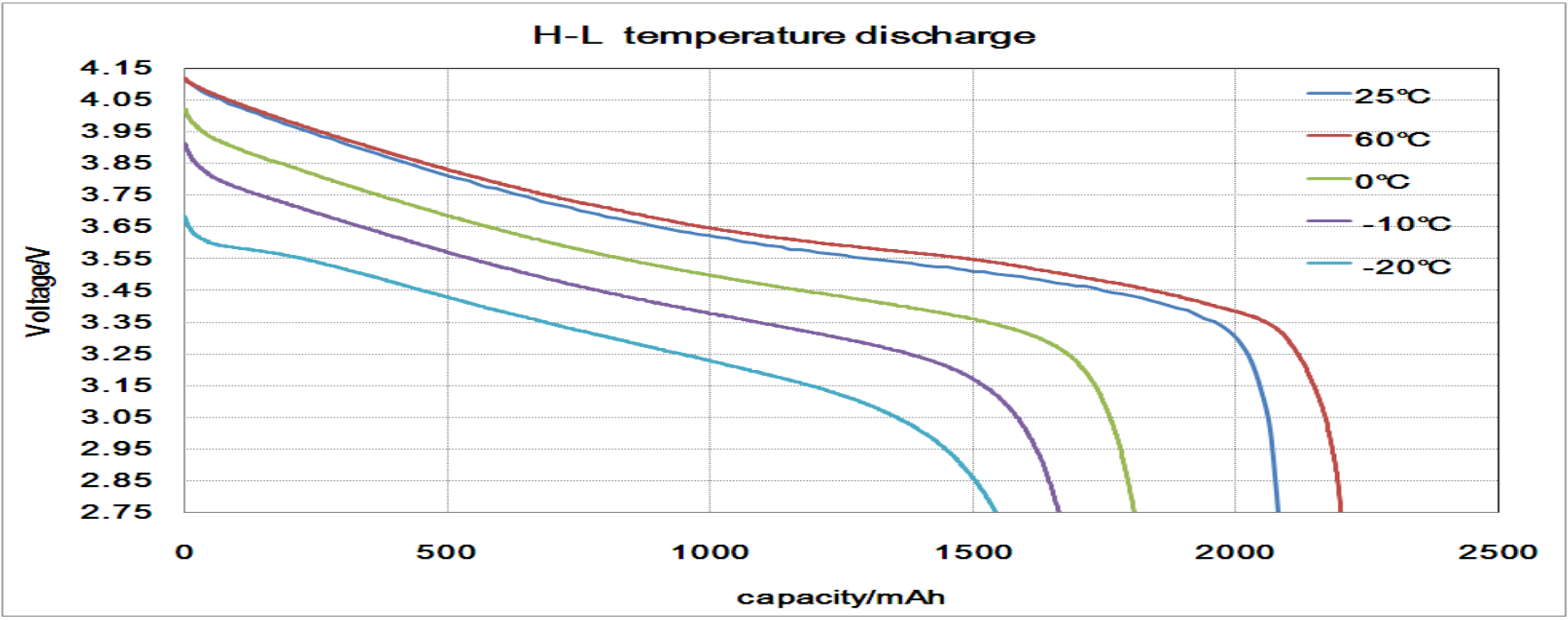
18650 EV 2.1AH Rate Performance



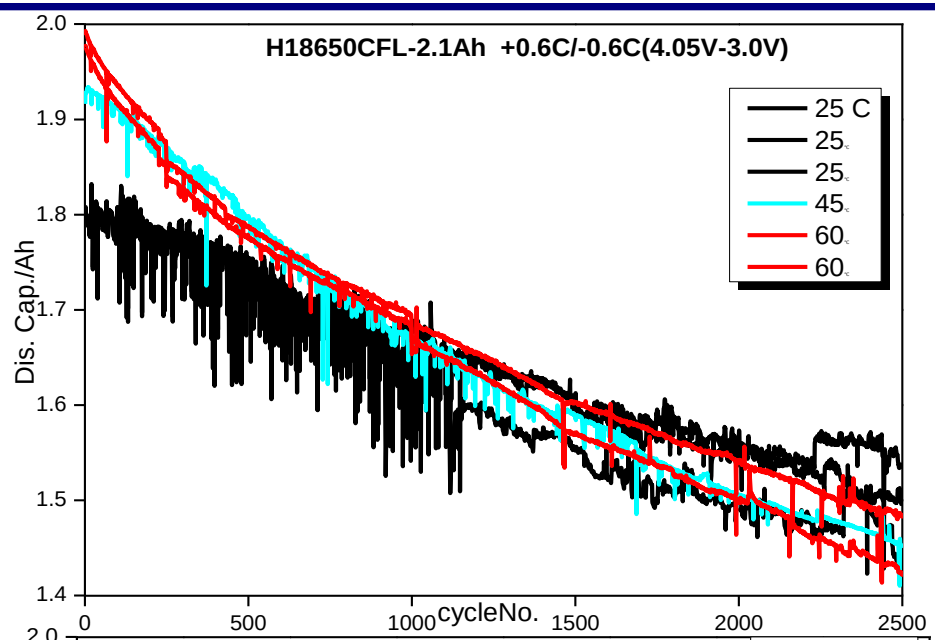
		0.2C	0.5C	1C	2C	3C	4C	5C	6C
Capacity/Ah	5#	2.15	2.09	2.04	2.02	1.91	1.39	0.74	0.24
	7#	2.15	2.08	2.05	2.03	1.91	1.40	0.77	0.25
Temperature rise/℃	5#	0.2	2.6	5.0	13.2	21.5	25.9	21.0	6.2
	7#	0.5	2.4	4.7	12.8	21.1	25.9	21.8	6.5

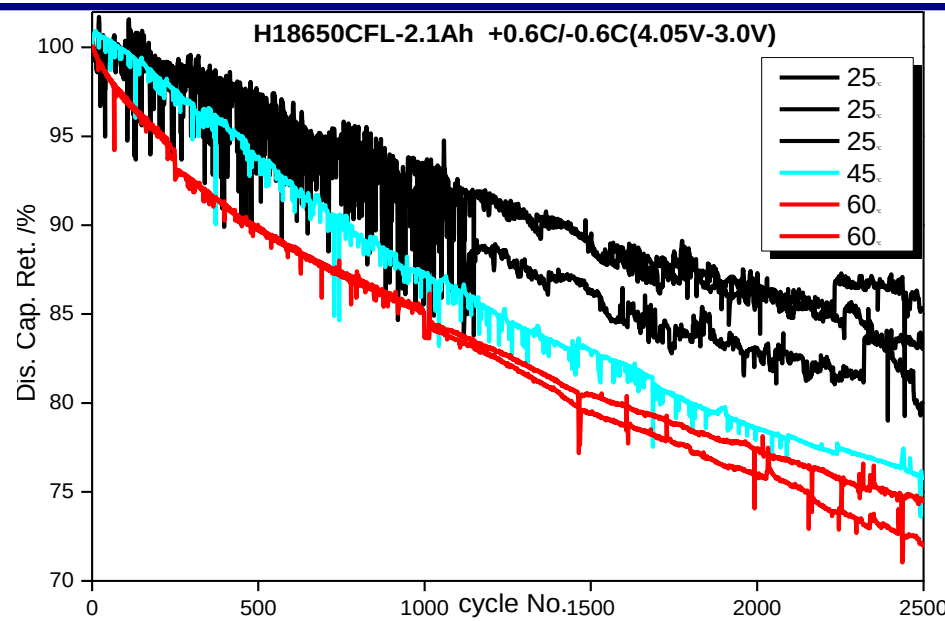
18650 EV 2.1AH high-Low Temp. Discharge Perf.

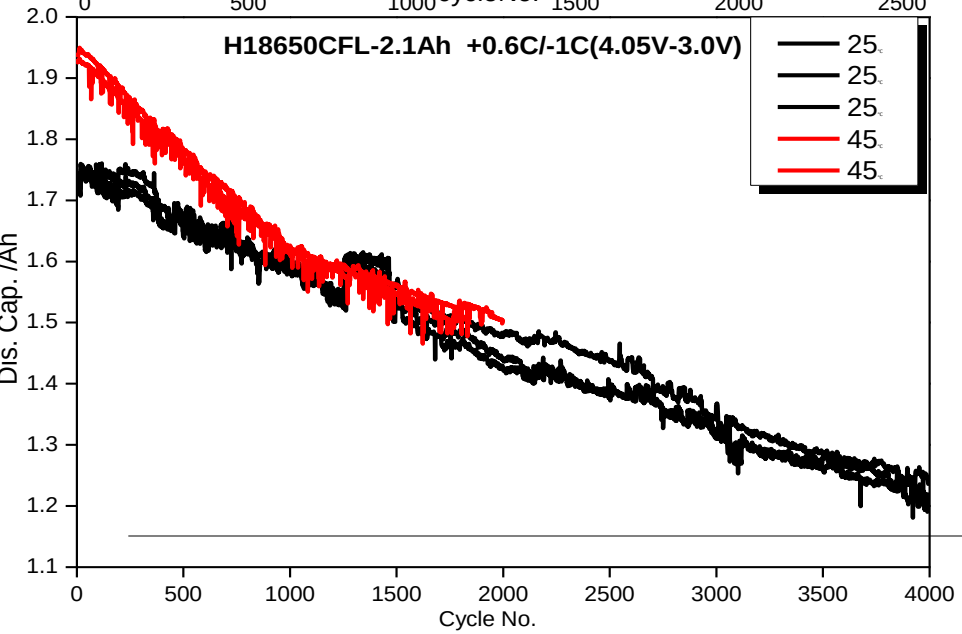
	0.5C capacity/mAh					60℃/25℃	0℃/25℃	-10℃/25℃	-20℃/25℃
	25℃	60℃	0℃	-10℃	-20℃				
09XA-17	2048.0	2172.0	1743.0	1601.0	1476.0	106.1%	85.1%	78.2%	72.1%
09XA-18	2077.0	2216.0	1797.0	1649.0	1527.0	106.7%	86.5%	79.4%	73.5%
09XA-19	2083.0	2201.0	1807.0	1665.0	1543.0	105.7%	86.7%	79.9%	74.1%

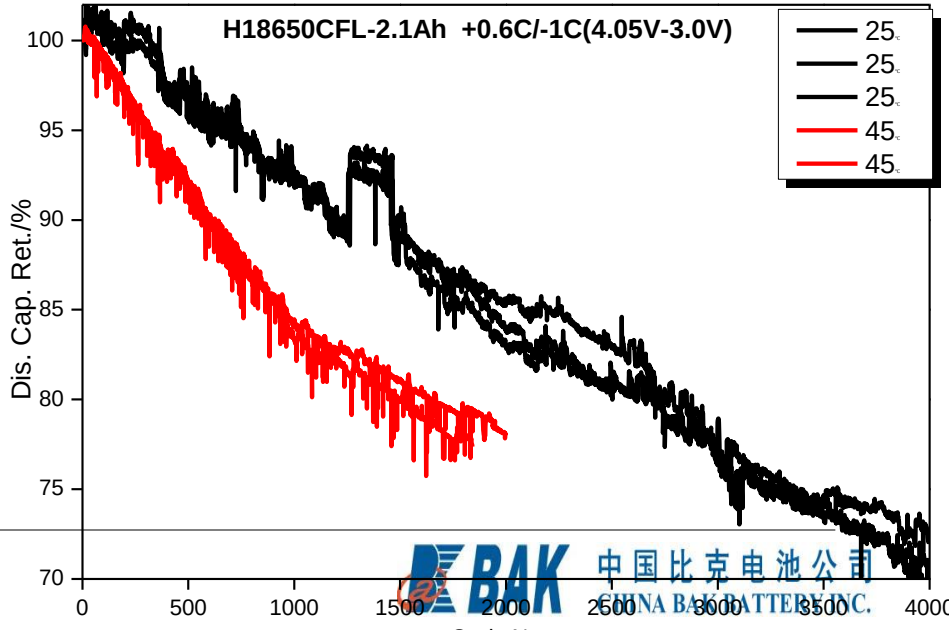


18650 EV 2.1AH Cycling Performance



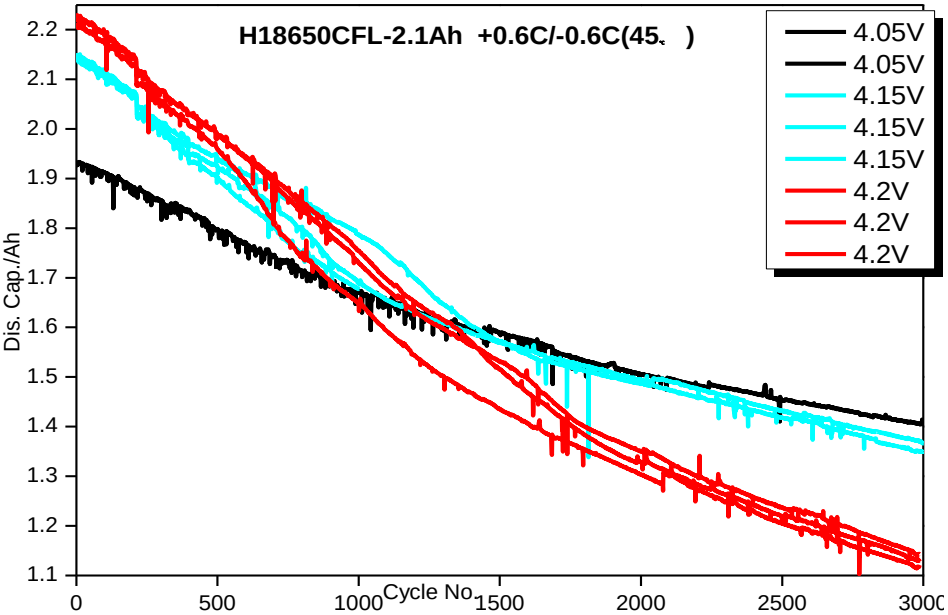


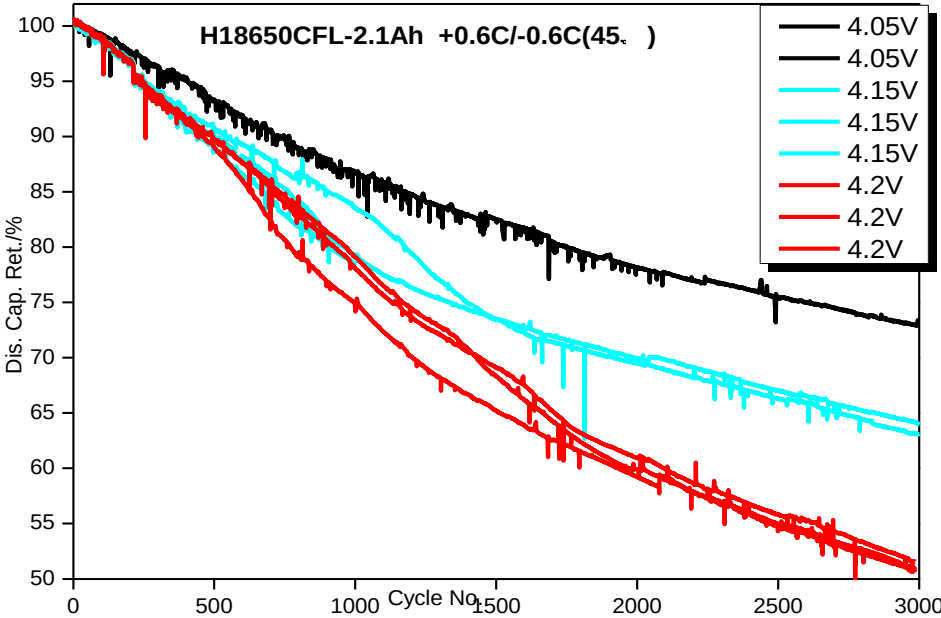


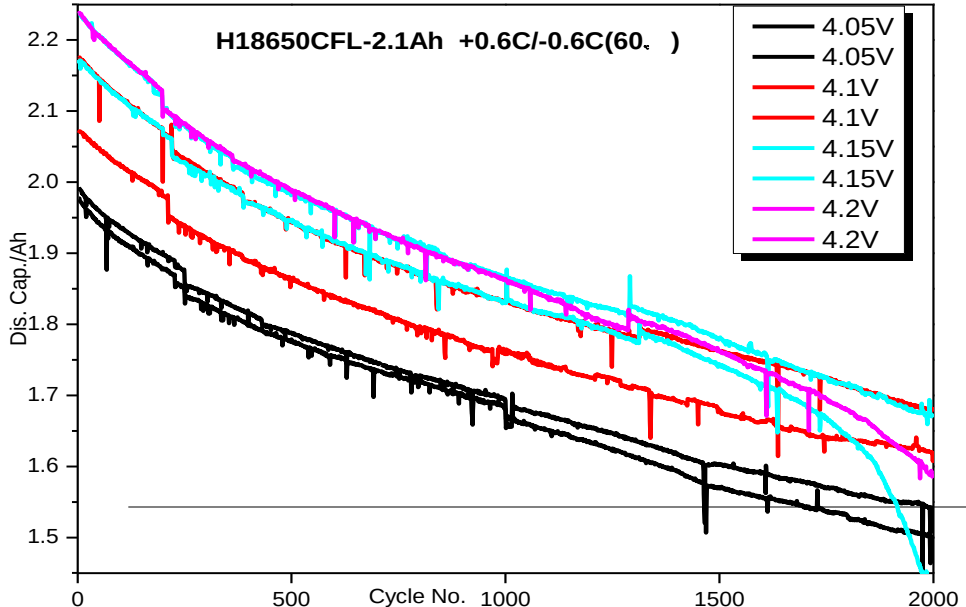


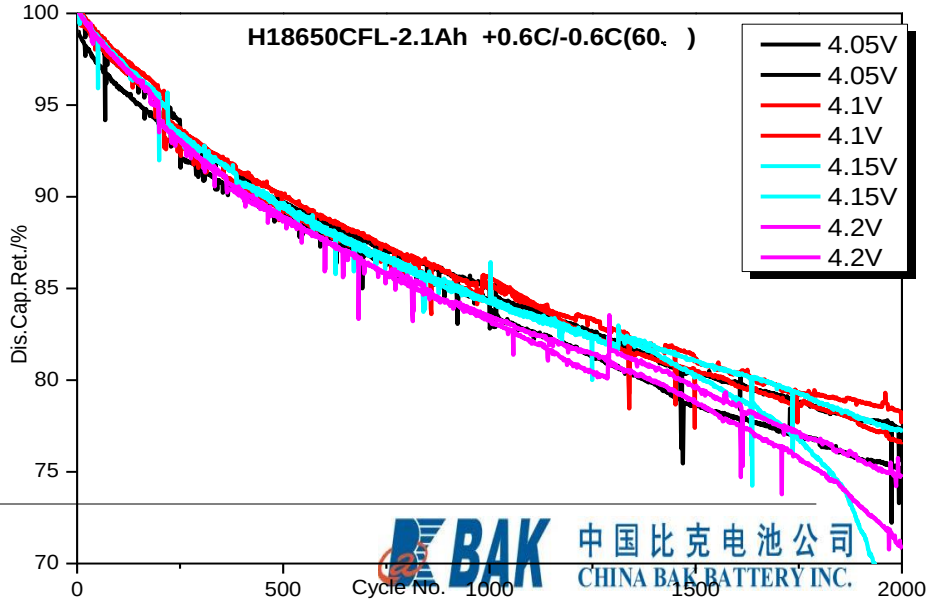
BAK 中国比克电池公司 CHINA BAK BATTERY INC.

18650 EV 2.1AH Cycling Performance





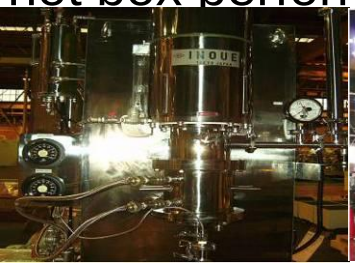


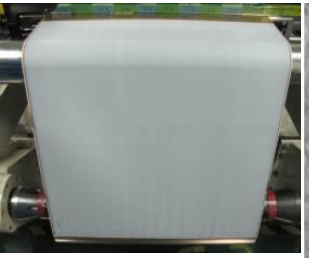


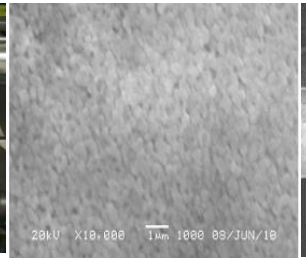
中国比克电池公司
CHINA BAK BATTERY INC.

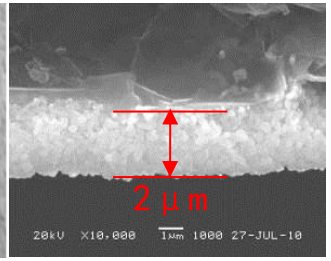
Safety Enhancement with Ceramic Coating

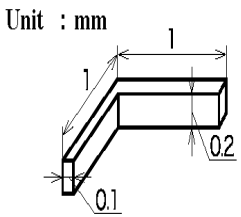
BAK can coat highly uniform safety layer on electrodes to improve internal short, hot box performance.



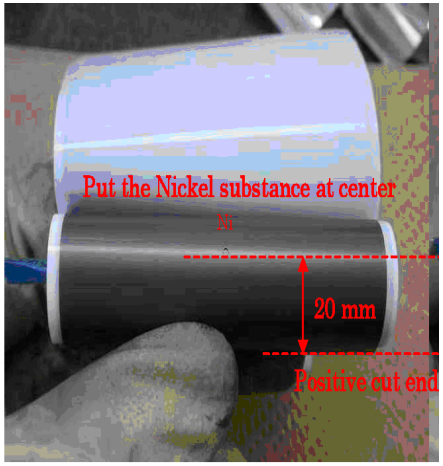








Metal particle size



cell with ceramic coating on anode					cell without ceramic coating on anode				
No.	cell No.	Metal particle size（μm）	Fire No.	Voltage disorder	No.	cell No.	Metal particle size（μm）	Fire No.	Voltage No.
1	25	50-100	0	0	1	25	50-100	2	8
2	25	50-100	0	0	2	25	50-100	0	13
3	25	50-100	0	0	3	25	50-100	0	1

Safety Enhancement with Ceramic Coating

Ceramic coating for hot box (150℃/10min).

cell with ceramic coating on anode					cell without ceramic coating on anode				
NO	phenomena	Surface Temp.	Atmos.Temp.	result	NO	phenomena	Surface Temp.	Atmos.Temp.	result
1	leak	160.5	150.0	Pass	1	fire	725.8	150.8	Fail
2	leak	160.7	150.0	Pass	2	fire	370.0	150.8	Fail
3	leak	162.6	150.0	Pass	3	leak	183.9	150.8	Pass
4	leak	159.0	150.0	Pass	4	leak	182.2	150.8	Pass
5	leak	154.9	151.7	Pass	5	fire	425.9	150.0	Fail

Ceramic coating on anode is used for EV batteries in BAK to improve thermal stability.

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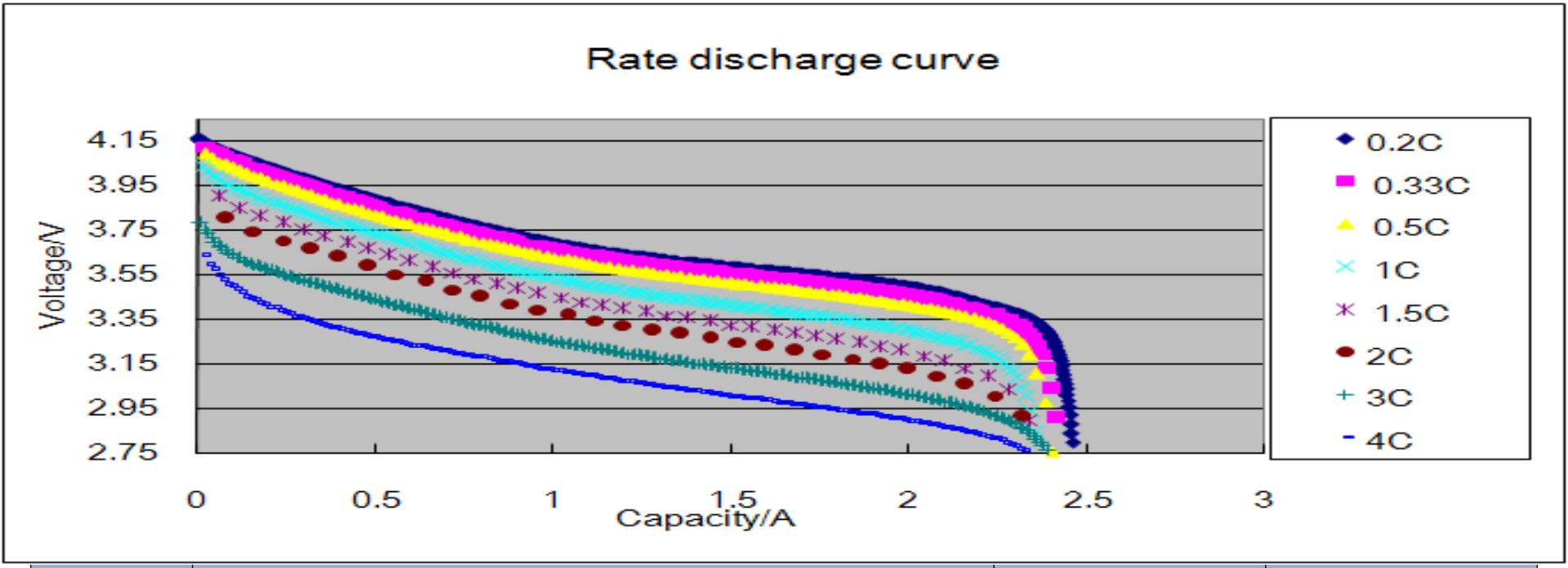
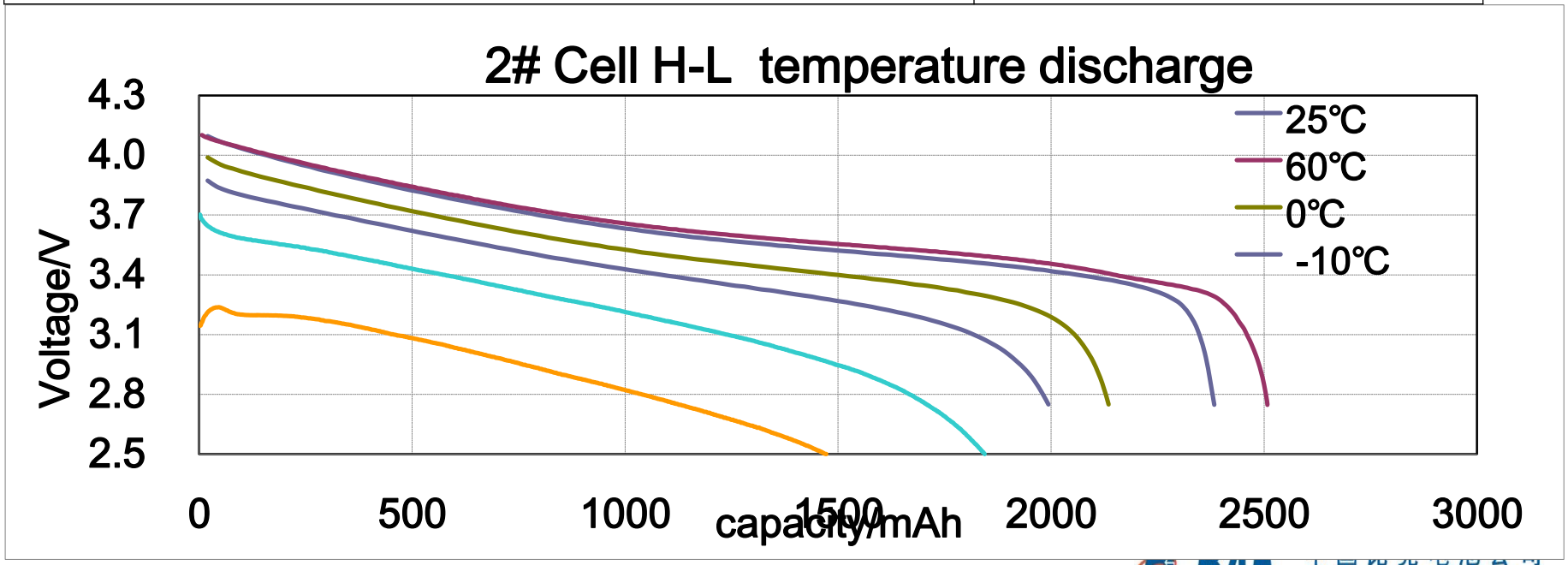
18650 EV 2.4AH Rate Performance



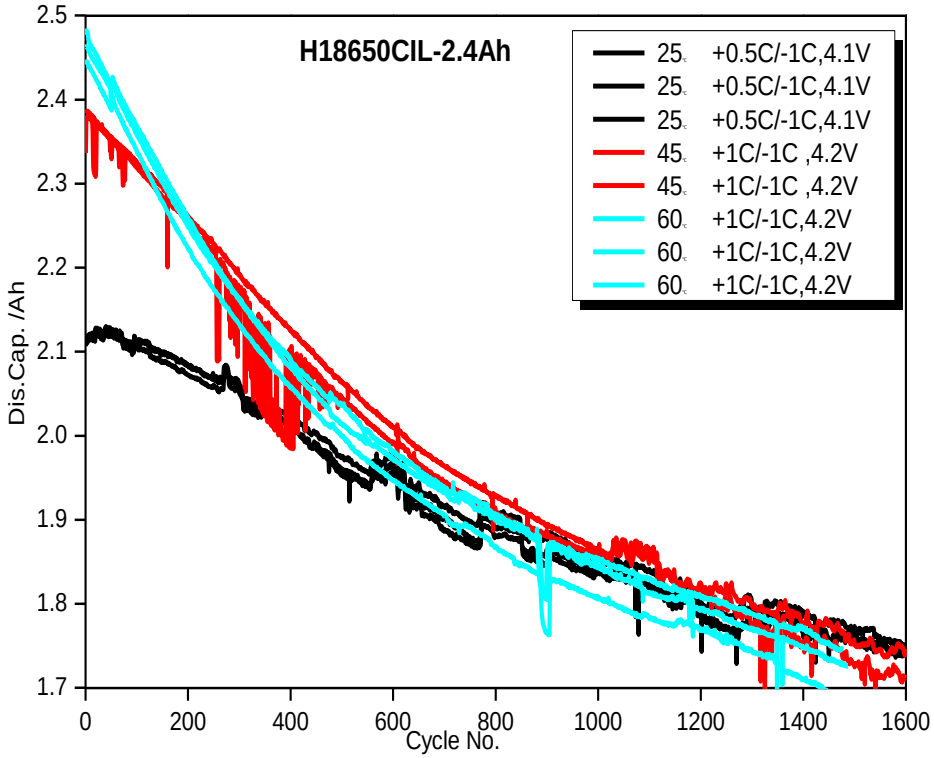
No.	Discharge Capacity (Ah)								1.5C discharge capacity/0.33C discharge capacity	4C discharge capacity/0.33C discharge capacity
	0.2C	0.33C	0.5C	1C	1.5C	2C	3C	4C		
1	2.463	2.428	2.401	2.371	2.368	2.375	2.398	2.331	97.5%	96.0%
2	2.454	2.429	2.400	2.371	2.365	2.372	2.386	2.320	97.4%	95.5%
3	2.465	2.429	2.398	2.370	2.368	2.376	2.388	2.320	97.5%	95.5%
Ave	2.460	2.429	2.400	2.371	2.367	2.374	2.391	2.324	97.5%	95.7%
Assessment									OK	

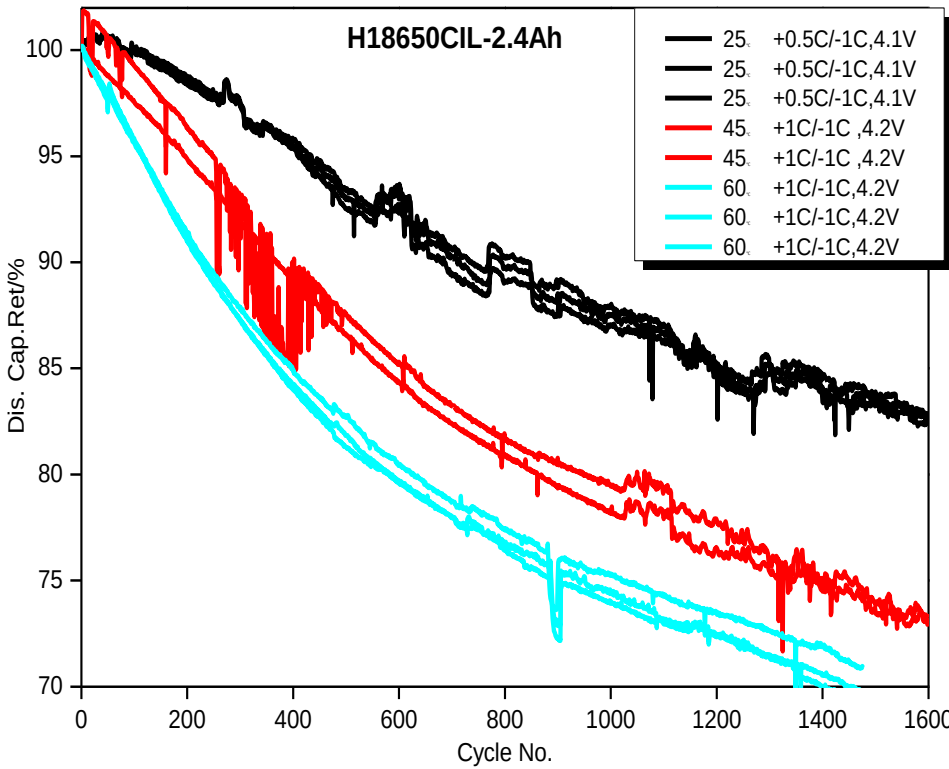
18650 EV 2.4AH High-Low Temp. Discharge Perf.

	25℃ Discharge Capacity (mAh)	60℃ Discharge Capacity (mAh)	0℃ Discharge Capacity (mAh)	-10℃ Discharge Capacity (mAh)	-20℃ Discharge Capacity (mAh)	-30℃ Discharge Capacity (mAh)	60℃ discharge capacity/25℃ discharge capacity	-20℃ discharge capacity /25℃ discharge capacity	-30℃ discharge capacity /25℃ discharge capacity
1	2395.0	2498.3	2123.9	1985.3	1823.6	1361.0	104.3%	76.1%	56.8%
2	2383.2	2507.9	2135.1	1993.8	1844.1	1472.4	105.2%	77.4%	61.8%
3	2397.2	2503.4	2150.3	2013.6	1895.2	1598.8	104.4%	79.1%	66.7%
AVE	2391.7	2503.2	2136.4	1997.6	1854.3	1477.4	104.6%	77.5%	61.8%
Assessment							OK		



18650 EV 2.4AH Cycling Performance





Electrolyte optimization: by optimizing solvents ratio and additives to reduce gassing, BAK EV 2.4AH can cycle up to 1600 times.

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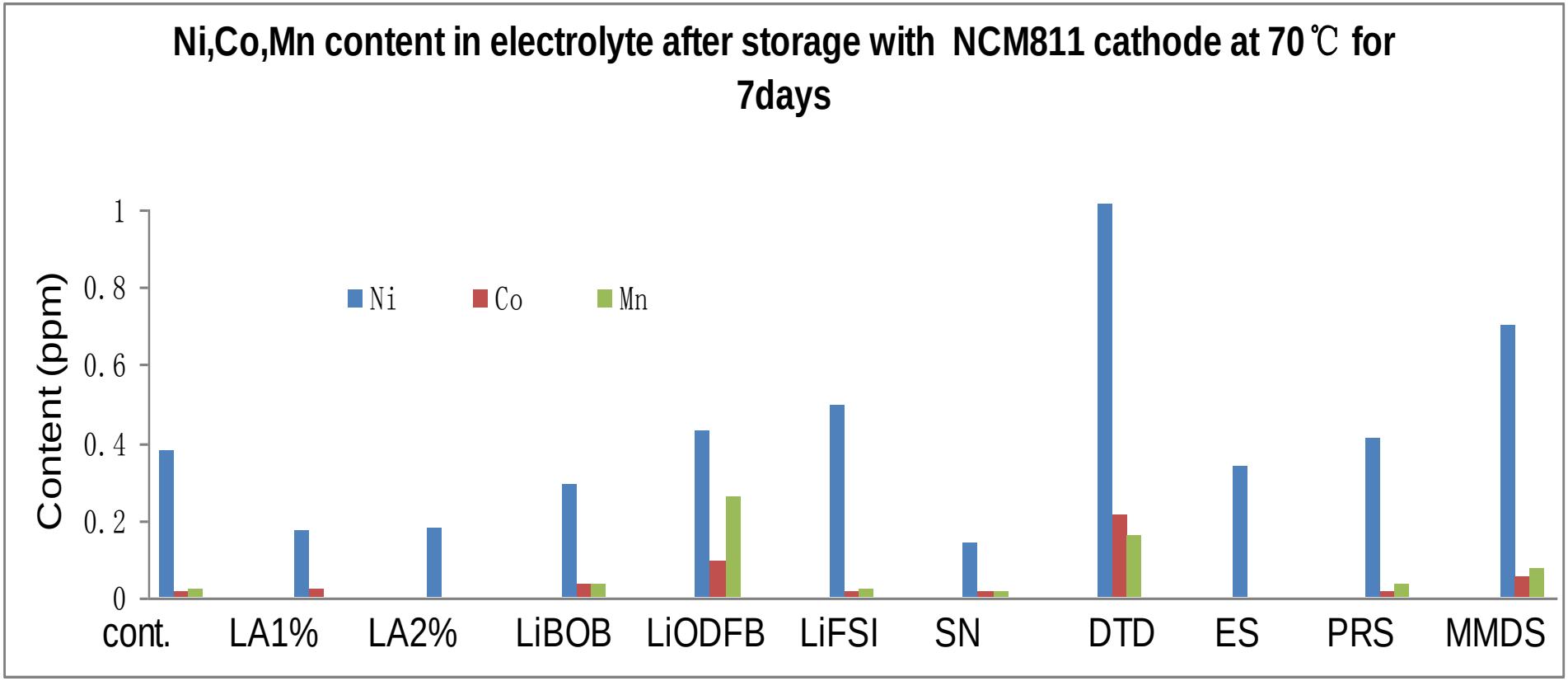
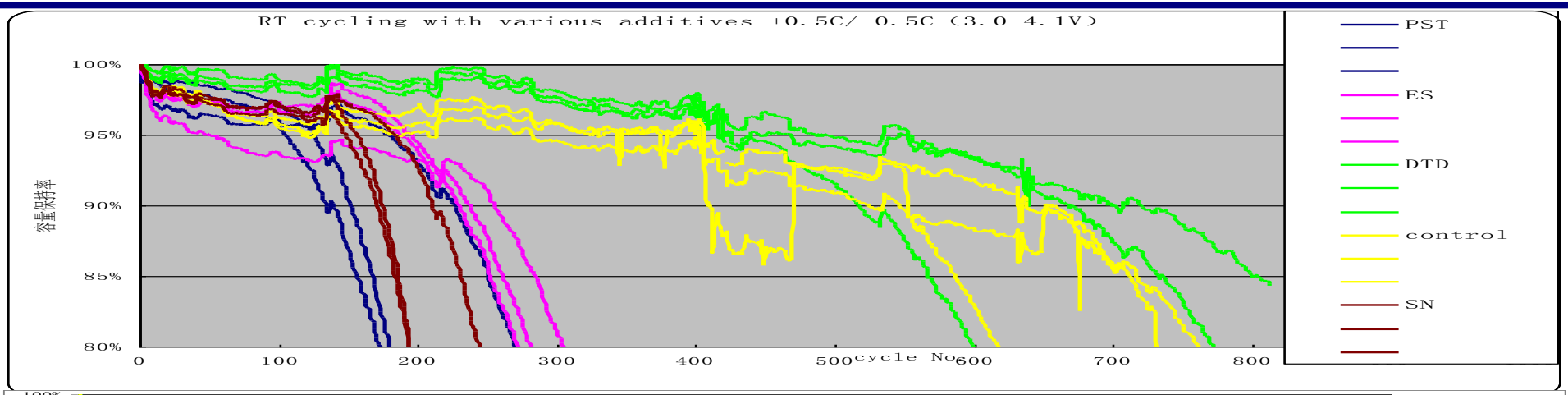
Electrolyte Additives for NCA/NMC811

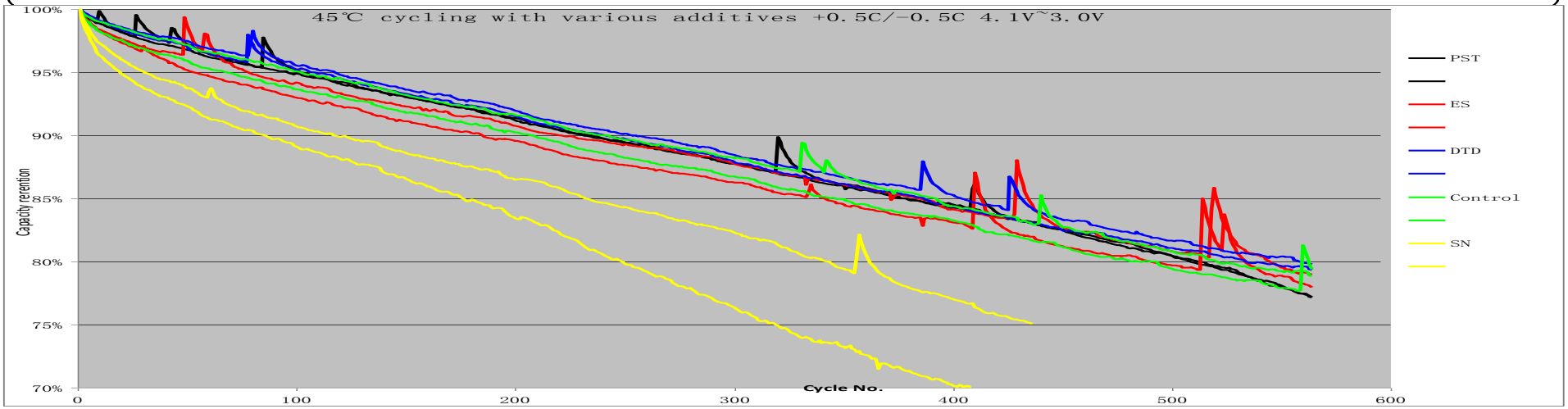
Blank: 15% LiPF6, EC:EMC:DMC=2:1:7, VC 1, FEC 2



- **LA and SN can obviously suppress Ni dissolution from NMC811 after HT Storage.**

Electrolyte Additives for NCA/NMC811

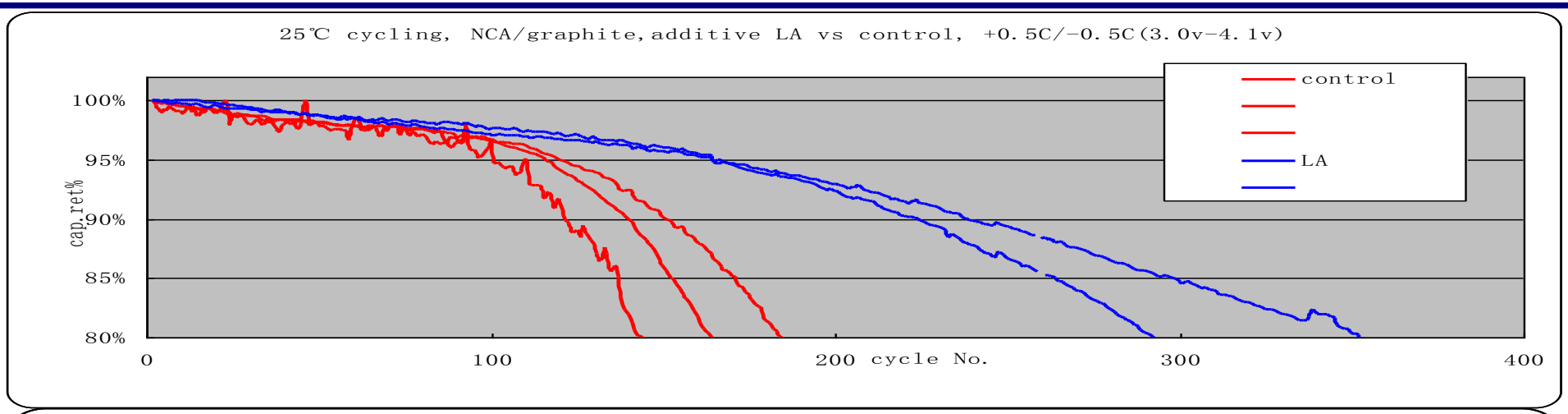


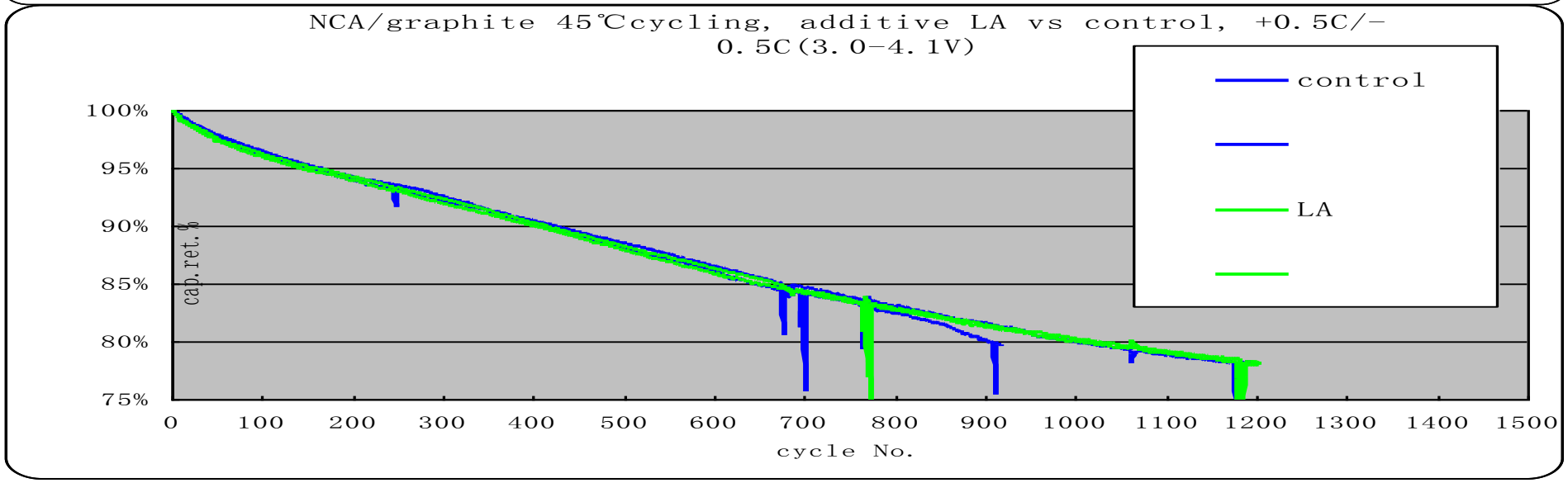


PRS,ES,SN deteriorate the RT cycling performance, while DTD slightly improves it.

For 45℃ cycling, due to strong gassing, additives don't make difference except SN.

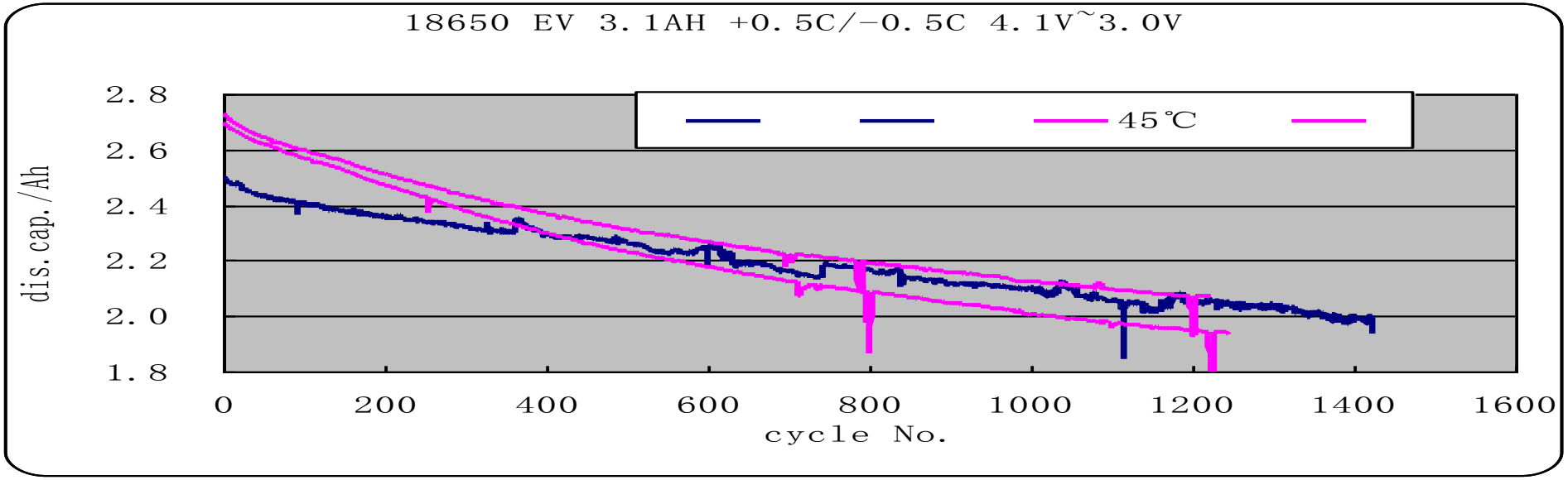
Electrolyte Additives for NCA/NMC811

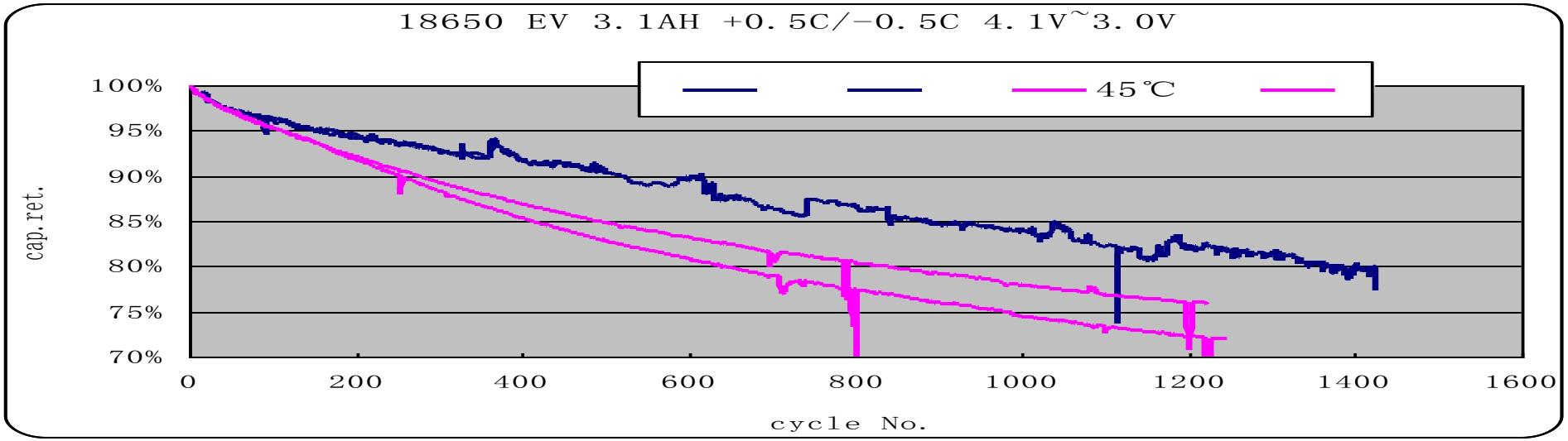




LA can greatly improves NCA RT cycling performance.

18650 EV 3.1AH Cycling Perf. after Electrolyte Optimization

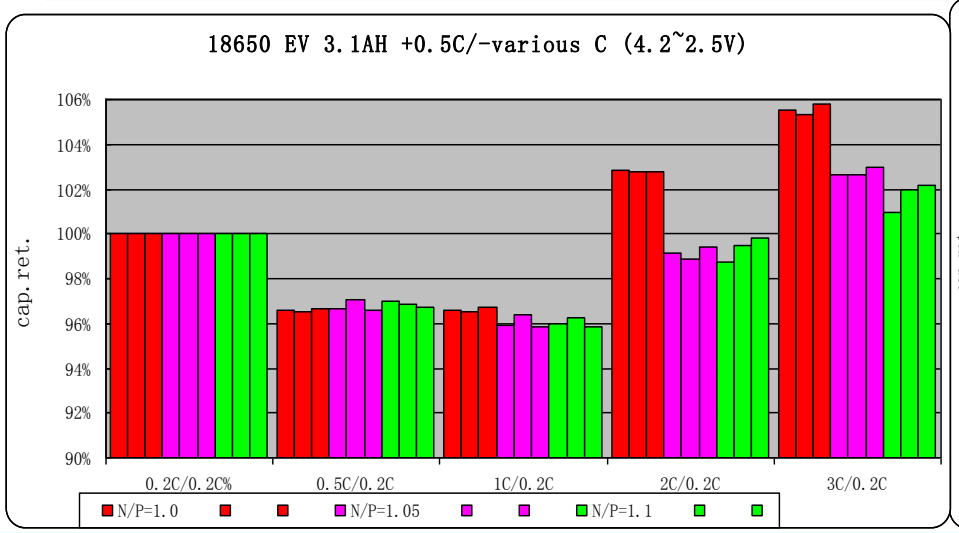


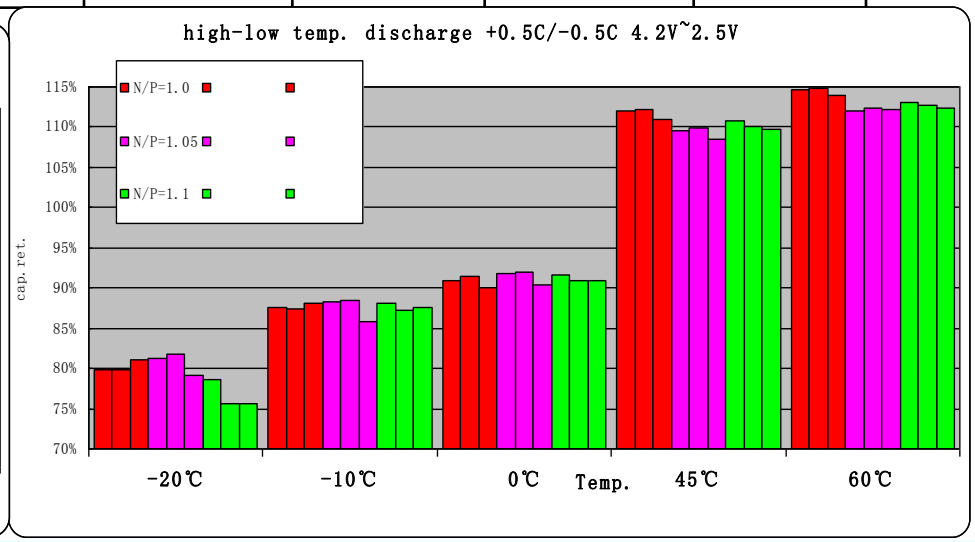


Anode Area Density Study (N/P Ratio)

We change N/P ratio to find a suitable value for capacity, cycling and safety balance.

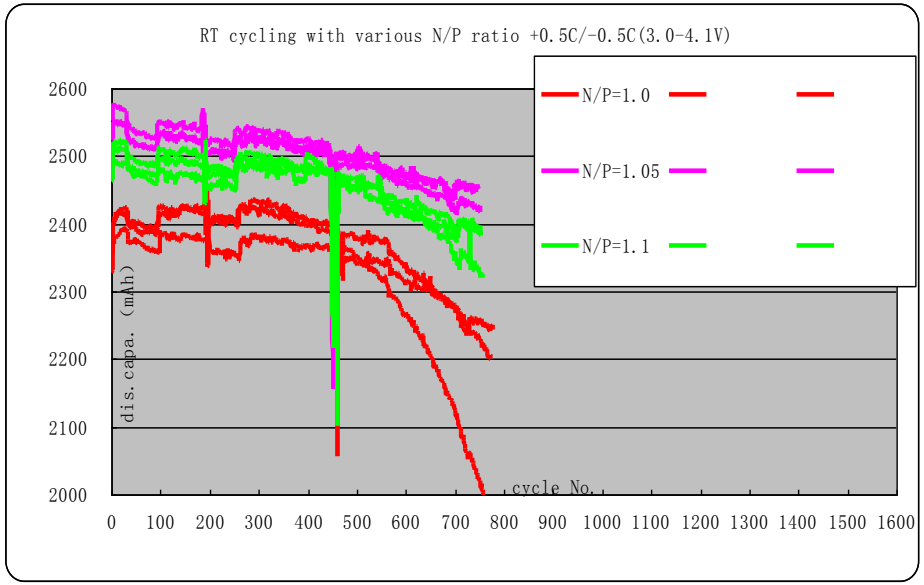
	Capacity sorting				0.2C precharge			
	0.2C		0.5C					
	Cap	C_+	Cap	C_+	CHAR	DISCH	first effi.	C_+
N/P 1	**2771.8**	**170.2**	**2700.2**	**165.8**	**3364.3**	**2882.1**	**85.7%**	**176.9**
N/P 1.05	**2919.8**	**179.3**	**2849.1**	**174.9**	**3441.4**	**2970.9**	**86.3%**	**182.4**
N/P 1.1	**2922.8**	**180.2**	**2849.3**	**175.7**	**3447.7**	**2978.0**	**86.4%**	**183.6**

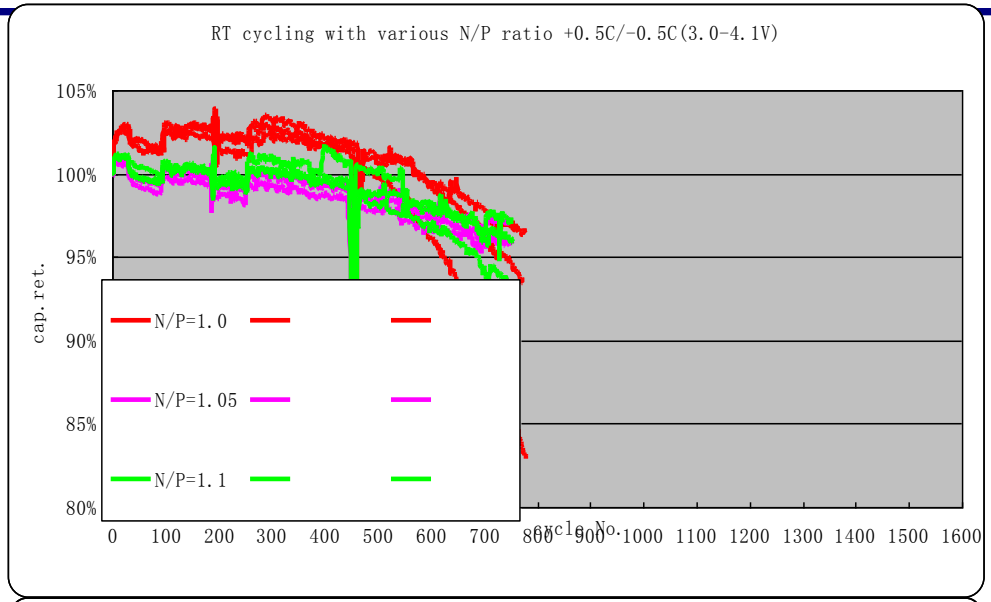


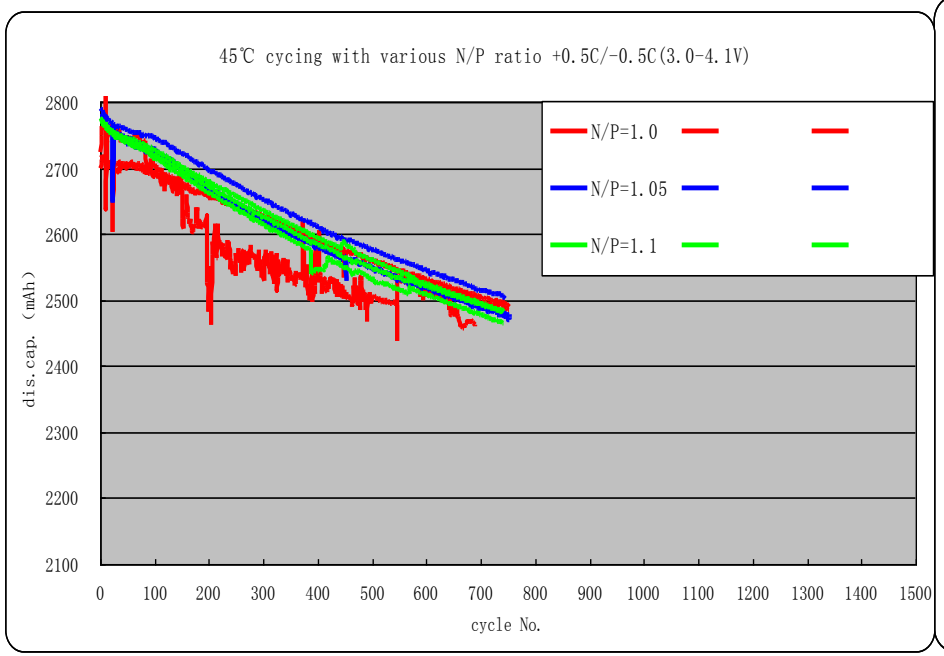


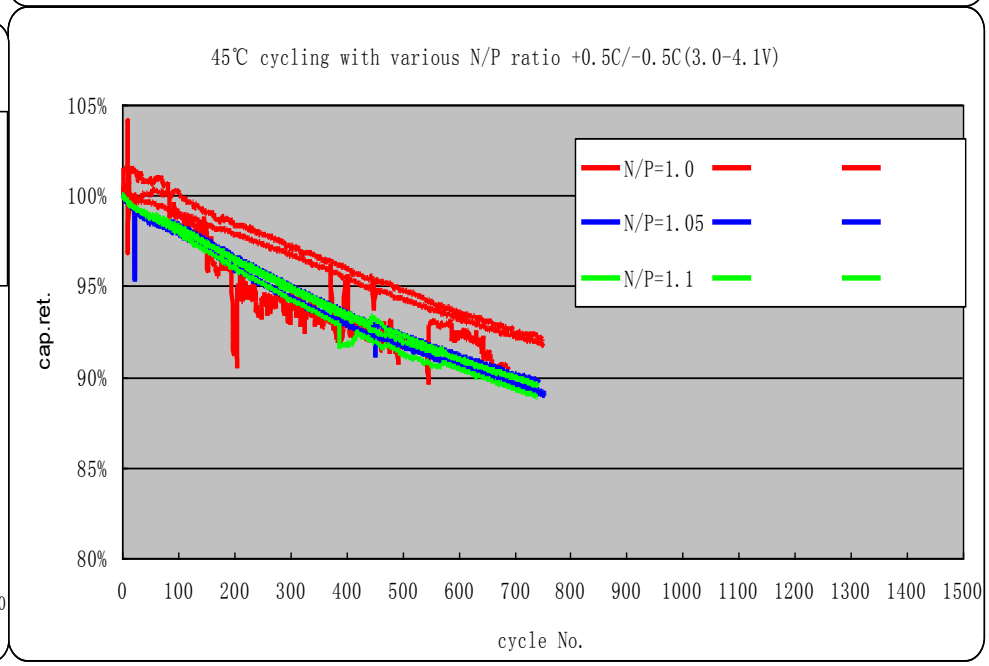
Increasing N/P ratio can increase capacity, but lower the rate performance and low temp.discharge performance.

18650 EV 3.1AH Cycling Performance

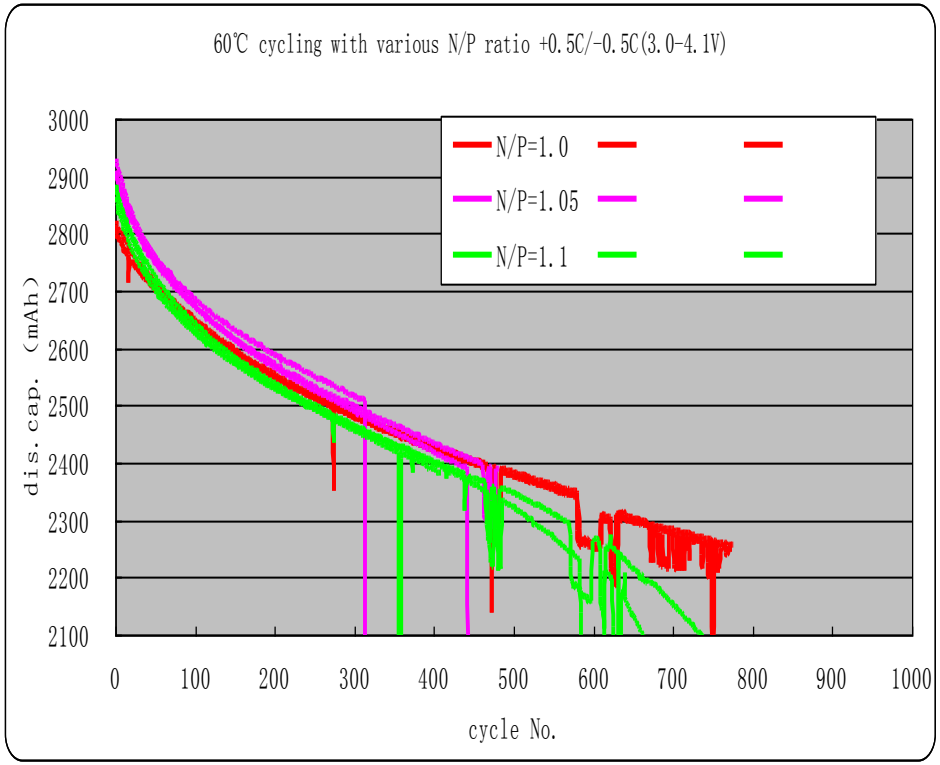


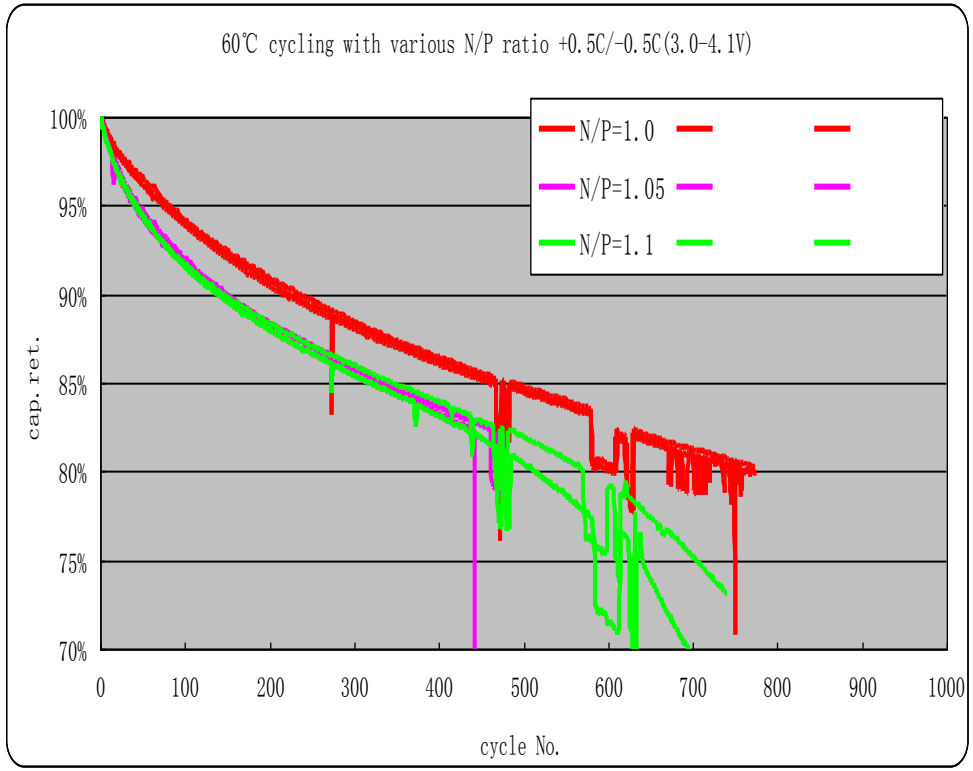






18650 EV 3.1AH Cycling Performance



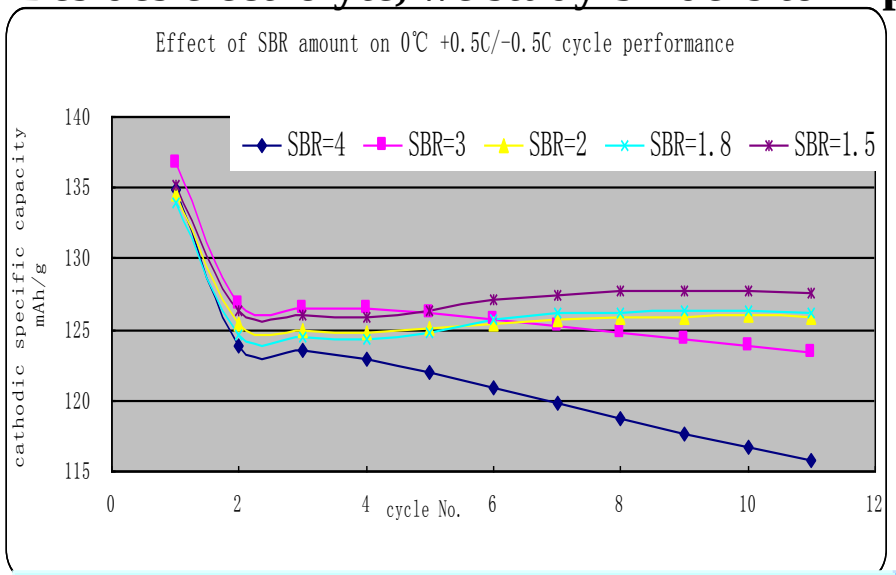


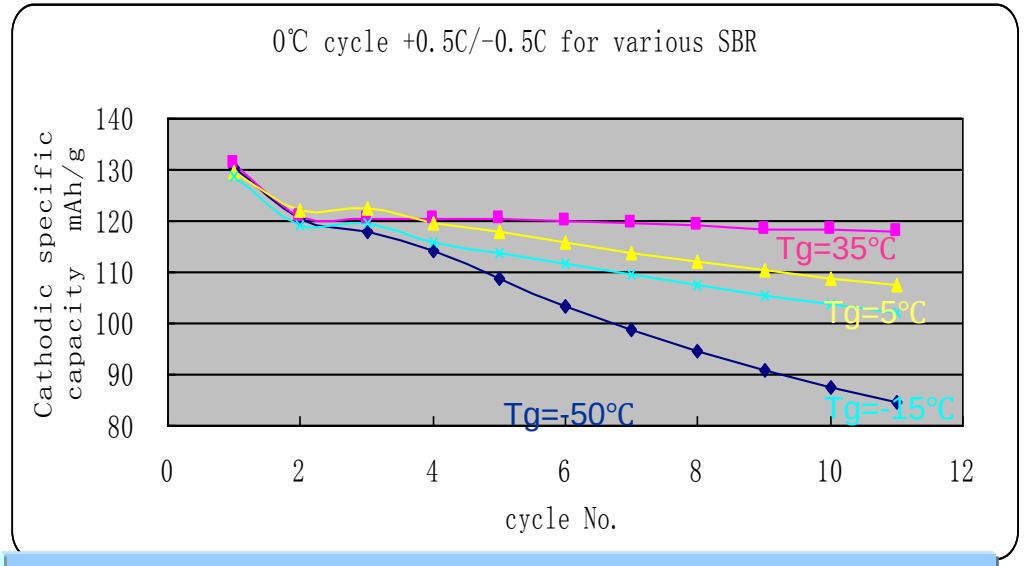
The lower N/P ratio ⟶ lower cathode potential when charging ⟶ less lithium deintercalation from cathode and less discharged capacity.

Lower cathode potential ⟶ less side reaction with electrolyte ⟶ better cycling performance.

Binder Study

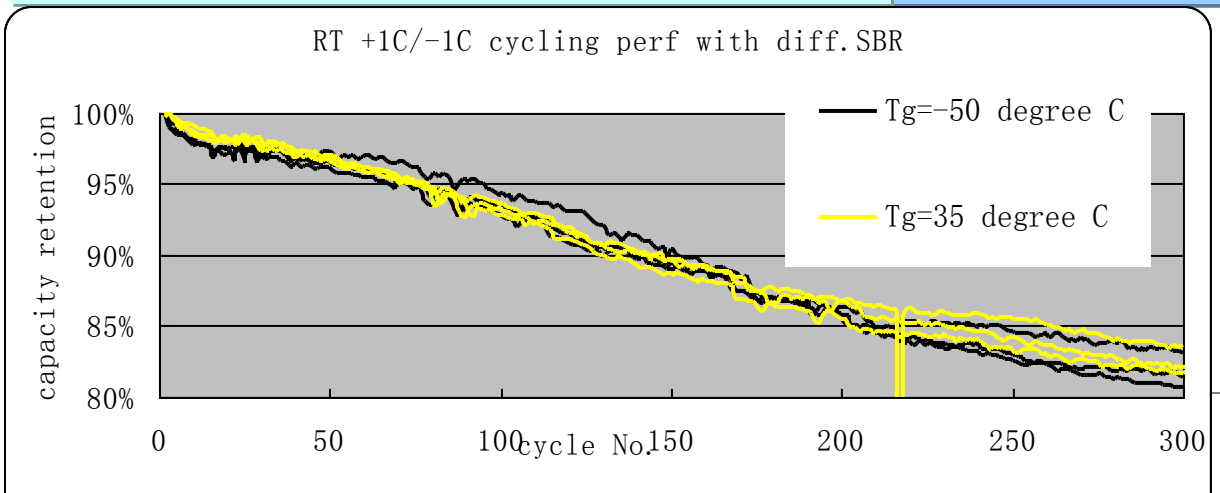
Besides electrolyte, we study binders to improve low temp. and fast charging perf.





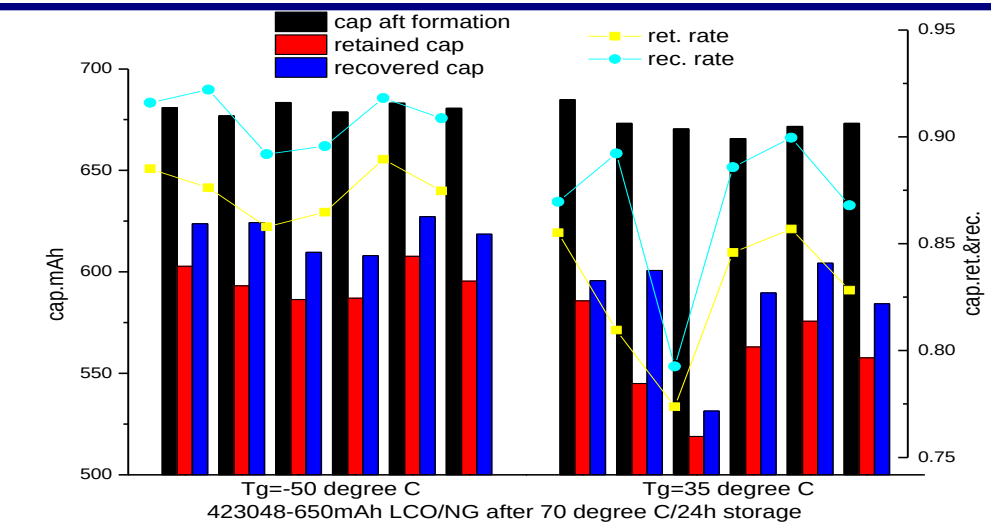
The higher SBR amount, the worse low temp. cycling performance.

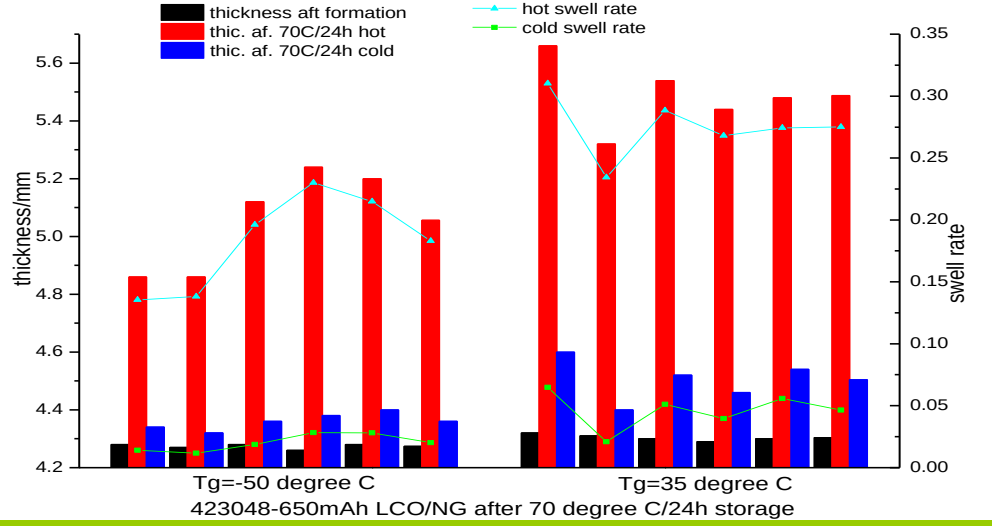
The higher Tg, the better low temp. cycling performance.



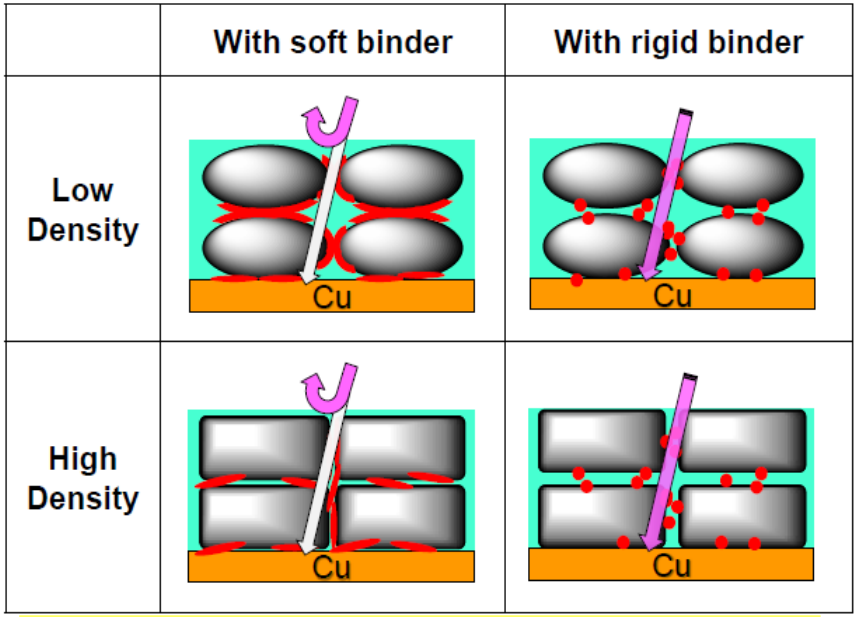
SBR with different Tg do not greatly influence RT cycling perf.

Binder Study





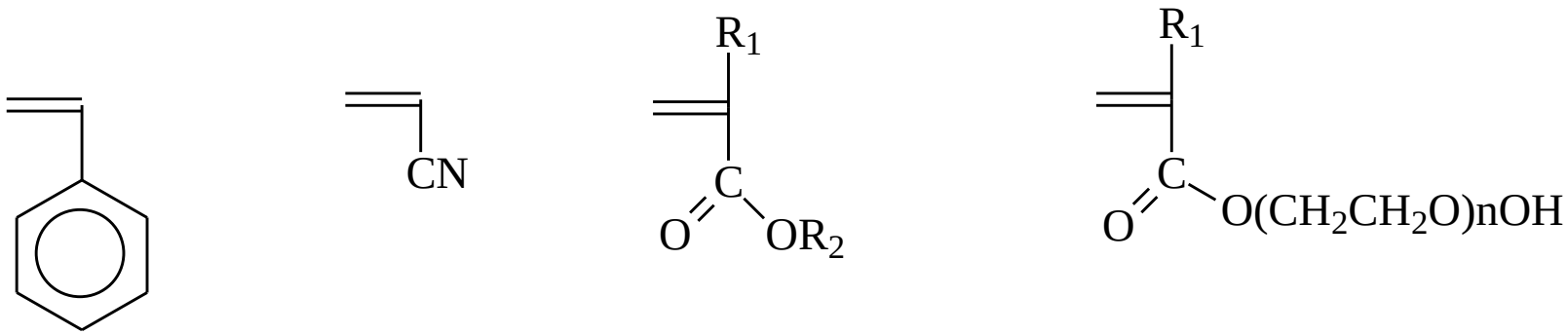
Tg is important for low and high temp. perf.



JSR: With rigid binder(high Tg), lithium ion pathways are preserved under dense electrodes, resulting less press density, but better low temp performance.

Soft binder (low Tg) will result in higher press density and better high temp. perf., which also acts as a preformed SEI.

Binder Synthesis



Polystyrene: stability

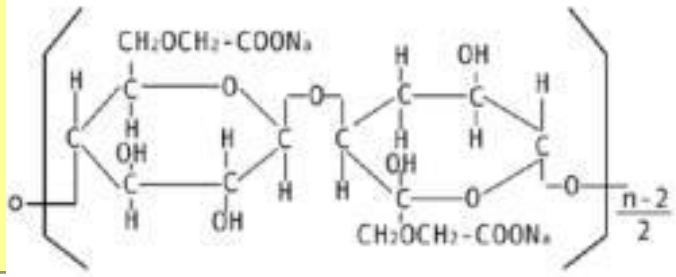
Polyacrylonitrile: used to be a polymer electrolyte due to high polarity and high lithium ion mobility.

Polyacrylates: by adjusting R1 and R2 functional groups, we can control polymer polarity, Tg.

Poly(oxyethylene)acrylates: used to be a polymer electrolyte for high lithium ion mobility.

Fluorine-Substituted CMC Synthesis

CMC(sodium carboxymethyl cellulose) is a polyelectrolyte (single ion conductor). Due to strong bonding between -OCH2COO- and Na+, it is a bad ion conductor.



$$\left[C_6H_7O_2(OH)_3\right]_n + LiOH \longrightarrow \left[C_6H_2O_2(OH)_2OLi\right]_n + H_2O$$

$$ClCF_2COOH + LiOH \longrightarrow ClCF_2COOLi + H_2O$$

$$\left[C_6H_2O_2(OH)_2OLi\right]_n + ClCF_2COOLi \longrightarrow \left[C_6H_2O_2(OH)_2OCF_2COOLi\right]_n + LiCl$$

Contents

- **BAK Introduction**
  - Basic Information
  - Production and Detection Equipments
  - R&D Equipments
- **xEV Battery Research**
  - NMC Background
  - 18650 EV 2.1AH
  - 18650 EV 2.4AH
  - 18650 EV 3.1AH
  - 18650 EV 3.4AH
- **xEV Battery Industrialization**

18650 EV 3.4AH

- By combining high Ni content NCA/NMC811 and SiC anode, we have developed 3.4AH 18650 cells in lab.
- Electron conducting additive optimization
- Electrolyte additive optimization (very important!)
- Anode binder optimization (LiPAA, conventional SBR, new lab-synthesized binder, polyimide?)
- Copper foil optimization (better elongation!)
- SiC optimization (SiC or SiOx?)

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xEV Battery Developing Axis of BAK

2005
First Industrialization of LFP（Co-work with A123）

2006
BAK International Foundation
Focused on LFP

2008
Awarded National 863 "New Energy Vehicle" Program

2009
Developed and MP 2.0Ah NMC 18650 for EV

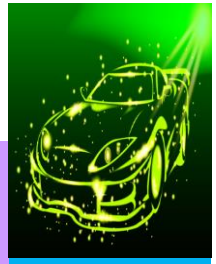
2010
27 Luxgen cars mounting BAK NMC 18650 were used in Taipei Flora Exposition

2011
200 Foton Taxis mounting BAK NMC 18650 started operation，over 100k km/car

2012
BAK NMC 18650 was awarded national "25 supporting new energy program"

2013
Co-worked with FAW to develop 4 Evs which entered "national new energy car list"

2014
Successfully developed 2.4Ah 18650
New sailing of BAK New Energy



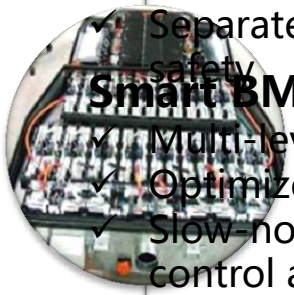
BAK EV Solution Introduction

NMC 18650 cell

- ✓ Low single unit energy-good safety
- ✓ High energy density
- ✓ Good high/low temperature performance
- ✓ Long lifespan
- ✓ Standard product, low cost, flexible configuratio

Standard Module

- ✓ Large number cell parallel improves uniformity
- ✓ Patent module design, balancing safety, strength, weight, reliability and cost
- ✓ Auto-manufacture
- ✓ Separate module to enhance safety



Smart BMS

- ✓ Multi-level safety control
- ✓ Optimized for extend lifespan
- ✓ Slow-normal-quick charge control and management
- ✓ Heat balance/management system
- ✓ Other option to extend battery performance

BAK EV Solution

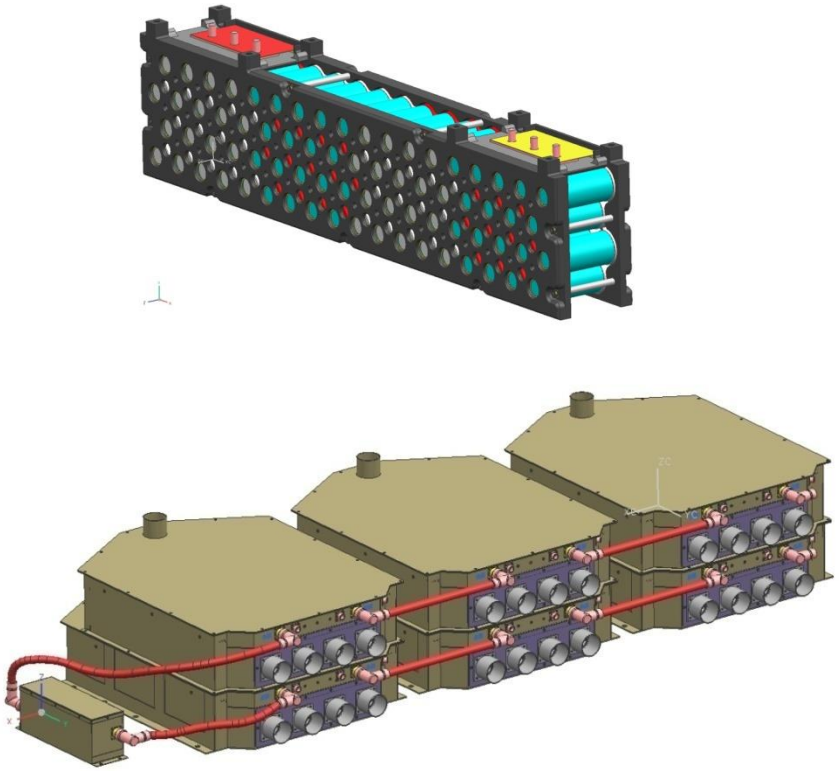
NMC 18650 + Standard Module + Smart BMS

First Chinese cell manufacturer to study, develop and successfully MP NMC 18650 for EV application

YUT HEV Project (LFP)

Spec:40Ah/576V Combination Mode:18P180S Cell model: 26650HP Car model: Bus HEV

① **battery pack picture**



② **bus picture using the pack**

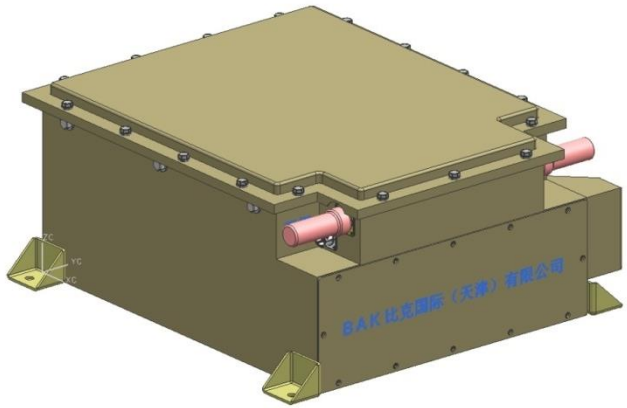
Singapore HEV Bus project (LFP)

Spec: 345.6V/57.2Ah, Combination Mode:108S/26P Cell model: 26650MP
Module number :120 Module Size:260*74.5*288.5mm

Wu Zhoulong PHEV Project (LFP)

Spec:70Ah/339.2V Combination Mode:25P106S Cell model: 26650MP Car model: PHEV

① **battery pack picture**



② **bus picture using the pack**

Bailujia Bus- SinoEV Project (LFP)

Spec:487.2Ah/403.2V Combination Mode:174P126S Cell model: 26650MP Car model: EV bus

① battery pack picture

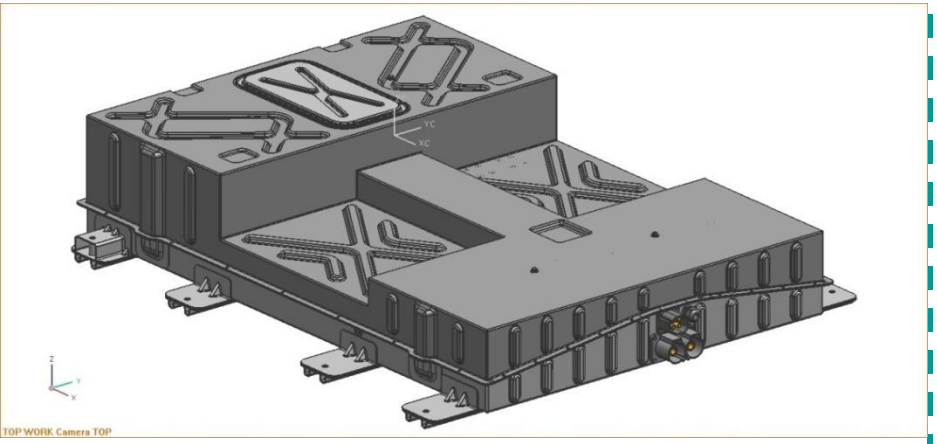
② bus picture using the pack

Great Wall Motors EV Project (LFP)

Shipment number： 7sets Spec:60Ah/320V Combination Mode: 9P100S

Cell model:36800FE Car model: Tengyi C20 EV

① battery pack picture

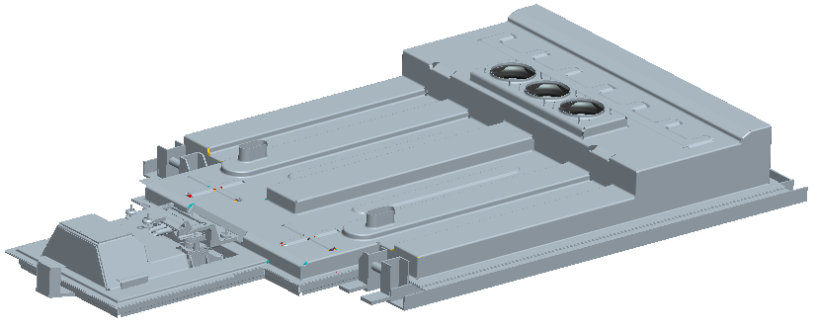


② car picture using the pack

Chery A5 EV Project (LFP)

Shipment number :3sets Spec:45Ah/332V Combination Mode:17P104S Cell Model: 26650MP Car model: A5 EV

① battery pack picture

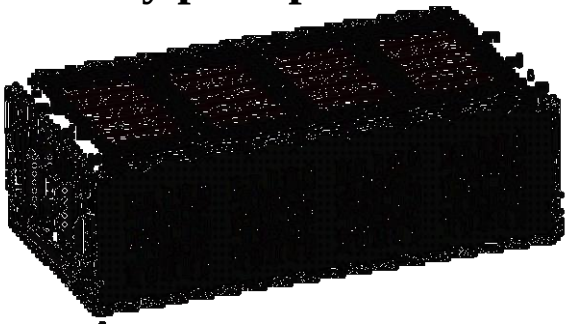


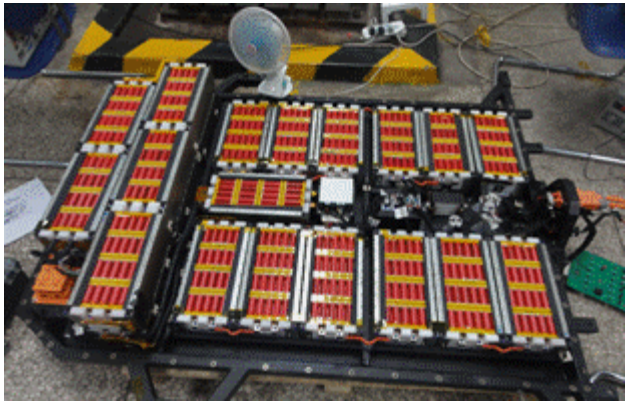
② car picture using the pack

FAW Qiming (Bora) Project (NMC)

Spec:70Ah/331V Combination Mode:33P92S Cell Model : H18650CFL2.1Ah
Car Model: Bora EV

① **battery pack picture**





② **car picture using the pack**

In 2012 VW MMD compaign，it achieved “the best driving experience” honor.

FAW B50 (NMC)

Spec:67.2Ah/302.4V Combination Mode:32P84S Cell Model: H18650CFL

① **battery pack picture**

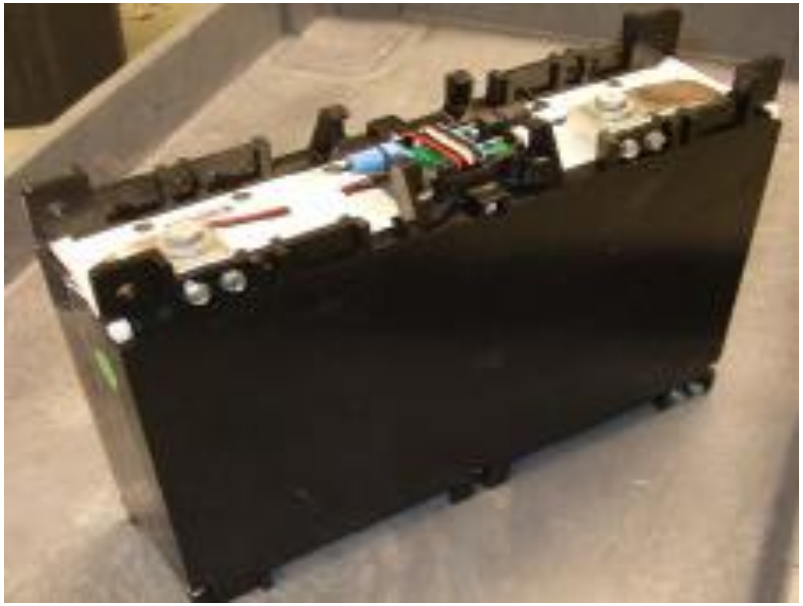
② **car picture using the pack**

100 Cars have been assembled using BAK batteries.

Yulong Huachuang (NMC)

Spec:106Ah/374.4V Combination Mode:53P104S Cell Model: H18650CB

① **battery pack picture**



② **car picture using the pack**

600 cars have been assembled from 2009 and no accidents.

Thank you for your atten

tion!