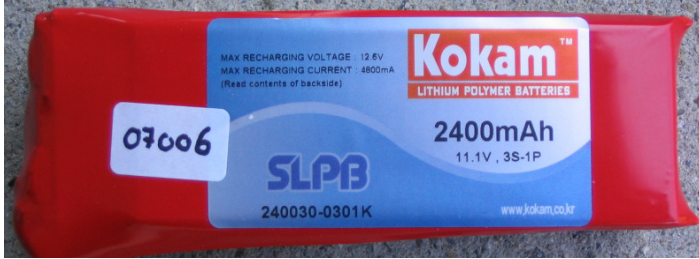


Technical Note
Cycle Life of LiPo Packs

N°: TN07006

Device under test	<p>Kokam 2400 3S1P H5 series (“30C”)</p> <p>Weight 232g incl. cable & connectors Dimension 115x32x30mm</p> 																														
Test method Test conditions	<p>a) Evaluation of dc discharge properties: $I_{dc} = 6C/12C/20C/25C/30C$</p> <p>b) Life test according to PA06002-v4 with the following settings: 410 cycles: $I_{charge} = 4.8A$, $V_{charge} = 4.2V/cell$, $V_{cutoff} = 3V/cell$ Discharge: $I_p = 72A$ (30C), $I_{average} = 25A$ (~10C), see appendix A for details</p> <p>c) Intermediate capacity measurements @ $I_{dc} = 28.8A$, $I_{charge} = 2.4A$, $V_{cutoff} = 3V/cell$</p>																														
Results																															
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Life test, 410 cycles (Fig. 2-10)																															
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Cell symmetry (Fig. 6 - 9)																															
The cell matching was not totally perfect. One cell performed with a slightly lower discharge voltage compared to the other two. However, it turned out that this was absolutely not critical for the useful cycle life as the observed difference became smaller throughout life test.																															
cont. next page																															

Conclusions & Comments

- The new Kokam 2400mAh cells have excellent discharge properties, similar to the previous tested 4000mAh cells. They can handle DC currents up to 25C without forced air cooling. Temperature rise and internal resistance are comparatively low.
- The cells are very rugged and a cycle life beyond 400 cycles can be expected even under harsh discharge conditions. The loss of capacity is with 1.5% per 100 cycles very low. At the same time the internal resistance increased by approximately 6% per 100 cycles which is a good result as well.
- This type of battery is qualified for high current burst discharges. The life test was performed with 72A bursts but the peak current limit is certainly higher.
- The cells of the tested battery had small discharge voltage differences but this was not relevant for cycle life.
- The discharge voltage curve has a characteristic decline after 2/3 of a full discharge but the average (V_m) is with almost 3.5V @ 28A on reasonable high level.
- The cells can be recharged with 4.8A (2C) without putting the cycle life at risk.

Date
2007-07-23

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jb

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No. of pages
10

DC discharge performance

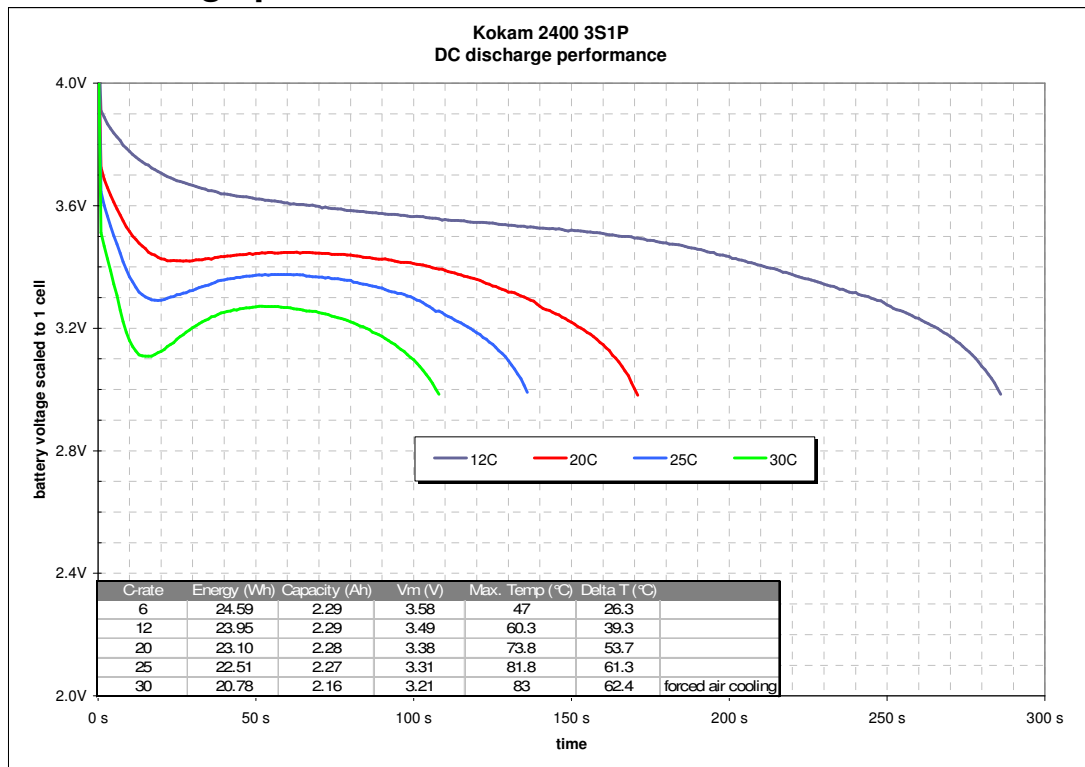


Fig. 1a, discharge performance before life test
 In order to prevent an overheating, the 30C discharge was done with forced air cooling (2.5m/s).

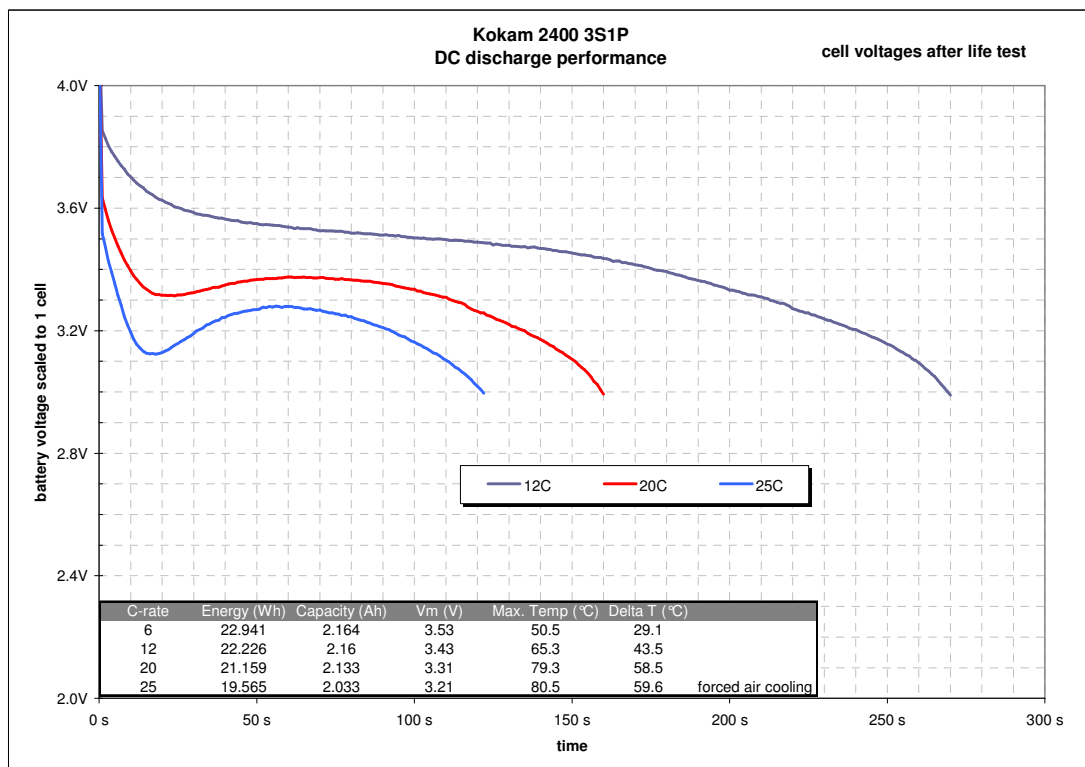


Fig. 1b, discharge performance after life test (410 cycles)

The loss of capacity after the life test was about 6% while the temperature rise increased by 10% for discharge currents of 12C and up. The 30C discharge was not repeated after life test (temperature rise!).

Life test results

Refer to appendix A for details about life test.

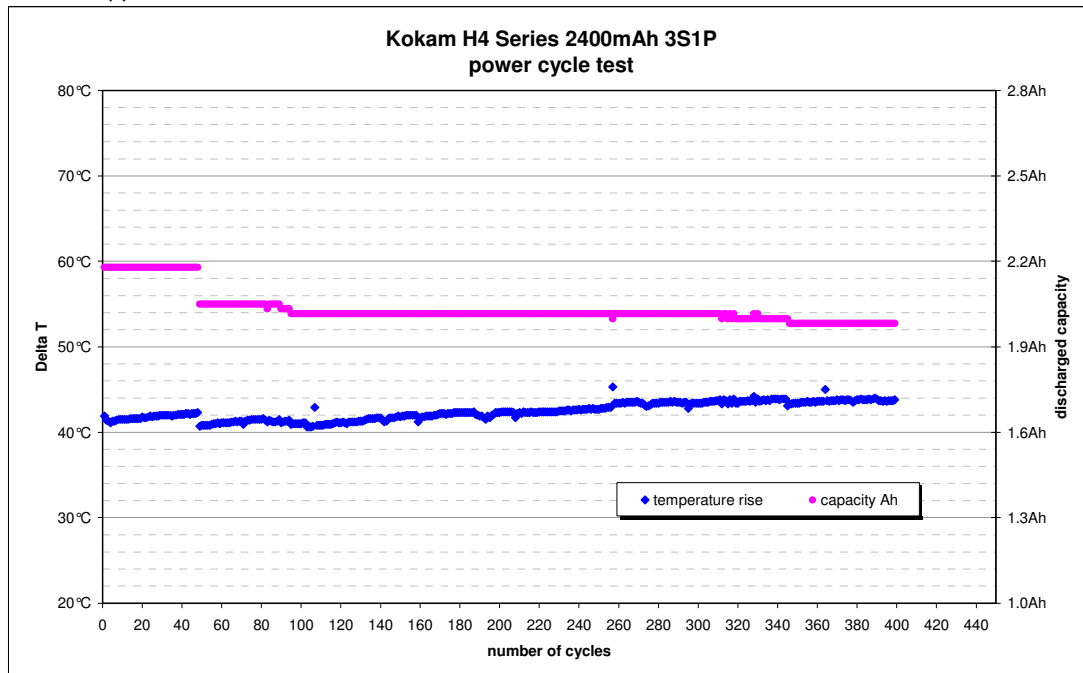


Fig. 2, discharged capacity and measured temperature rise cycle by cycle.

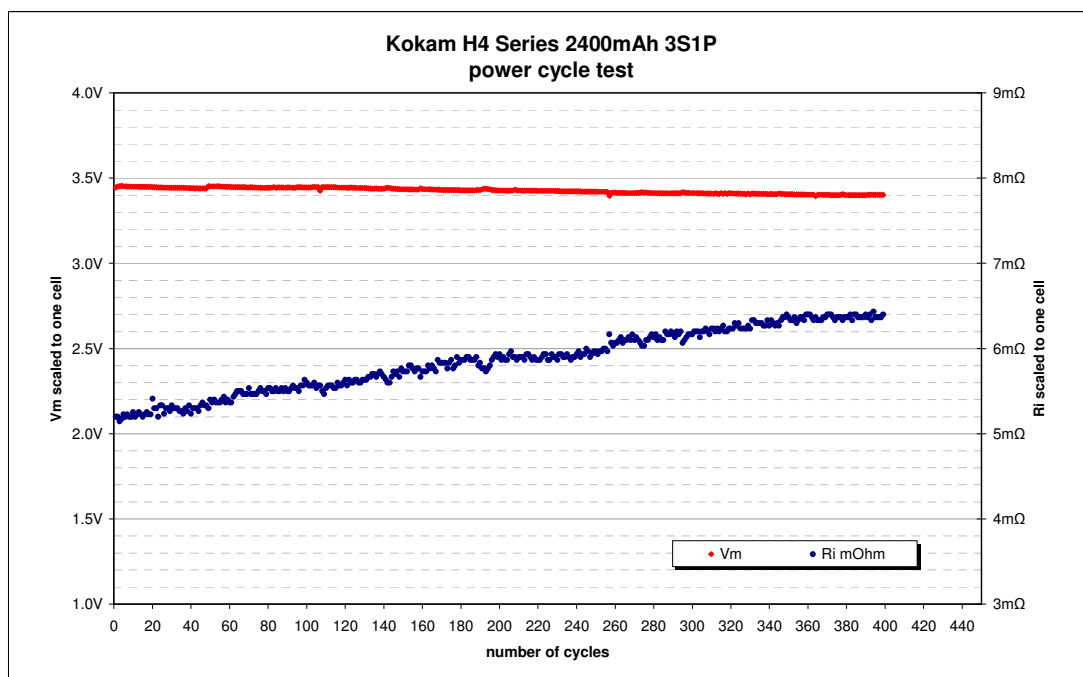


Fig. 3, discharge voltage Vm and internal resistance Ri vs number of cycles

The displayed Ri values are mean averages from the time period of 150s to 190s after beginning of discharge. This is precisely the time where the Ri reached its minimum (refer to Fig.6).

An increase of Ri from 5.2mΩ to 6.4mΩ was observed after 410 cycles in life test which is an increase of 23%.

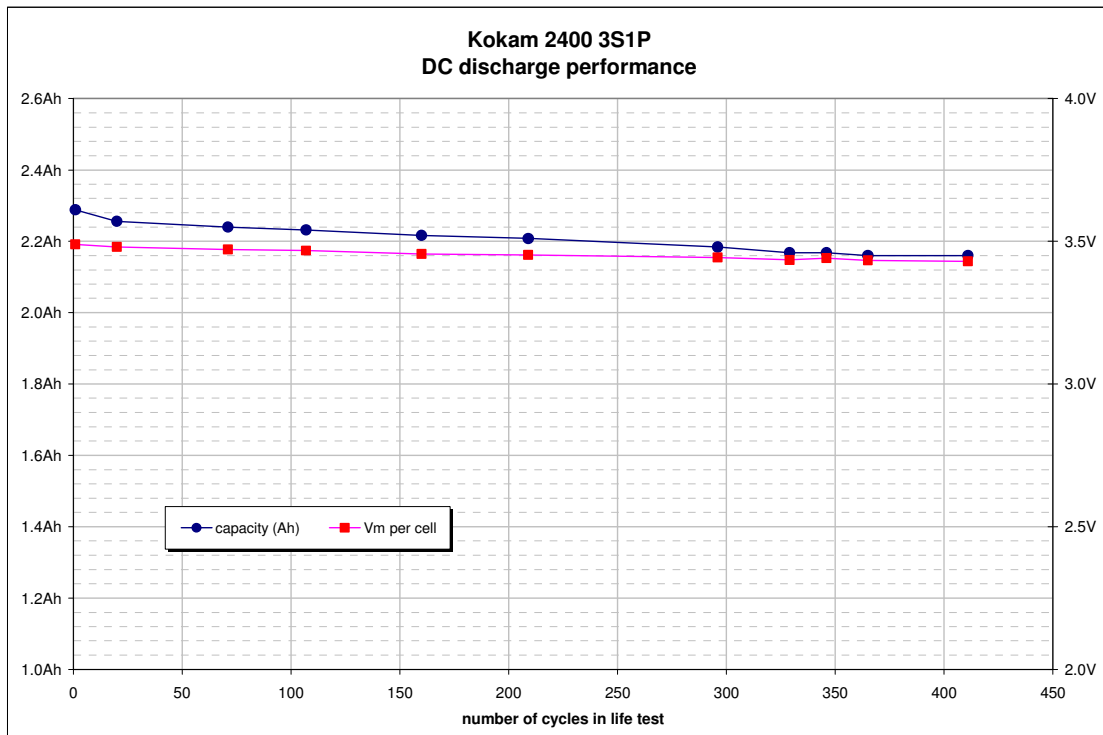


Fig. 4, trend of capacity vs. number of cycles. The capacity was measured @28.8Adc and Vcutoff = 3V/cell
 An 6% capacity drop was observed after 410cycles.

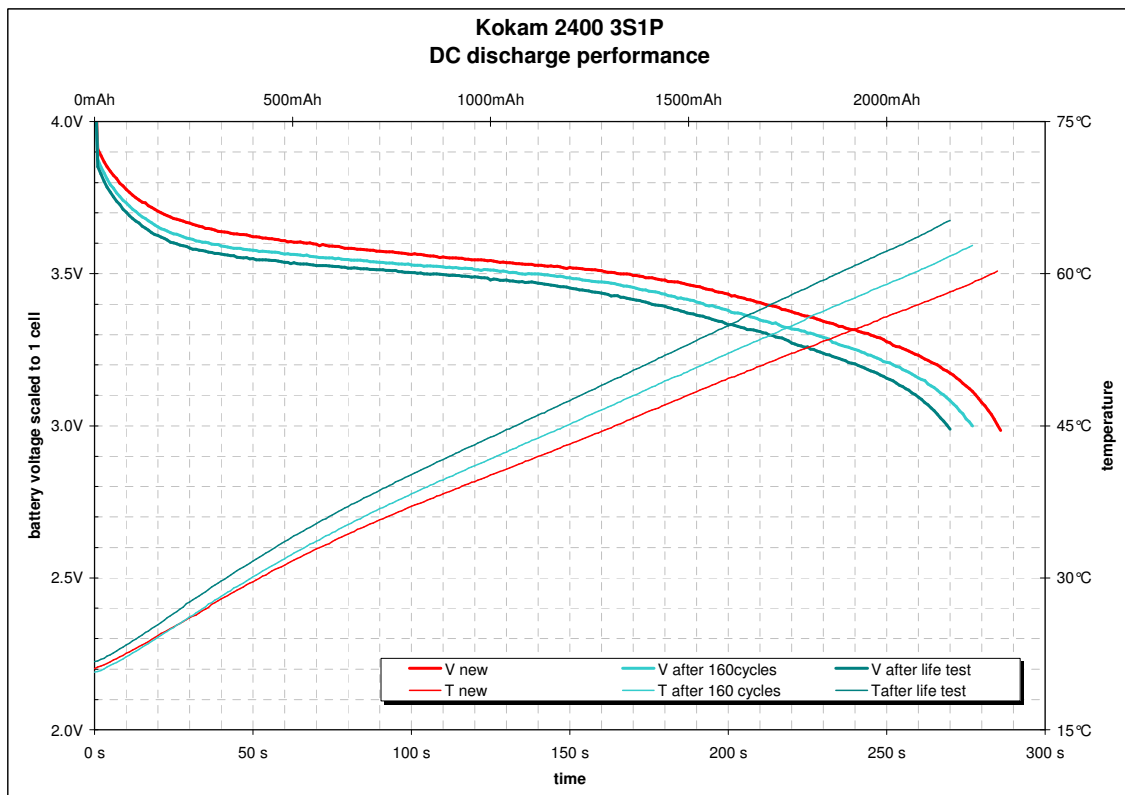


Fig. 5, comparison of the discharge voltage curves and temperatures @ 28.8A (12C)

Cell symmetry

Before life test

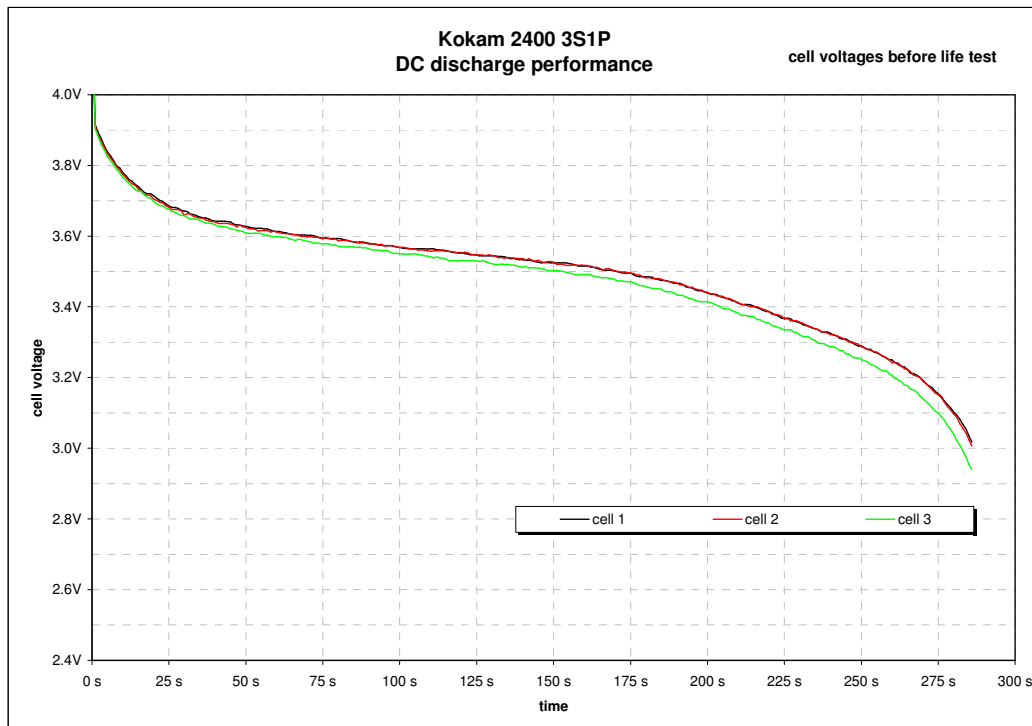


Fig. 6, cell voltages before life test during 28.8Adc discharge

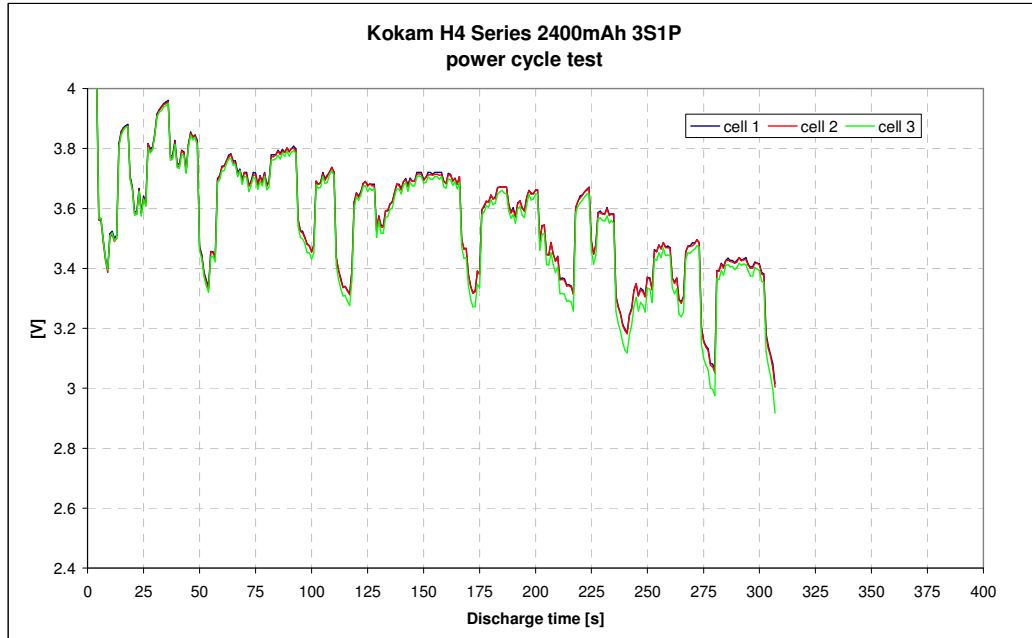


Fig. 7, cell voltages during the first cycle of life test

Two cells performed almost identical while the third one (cell 3) exhibits a lower discharge voltage. In the middle of the discharge period a delta V of about 20mV @ 12C and 50mV @ 30C can be observed.

After life test

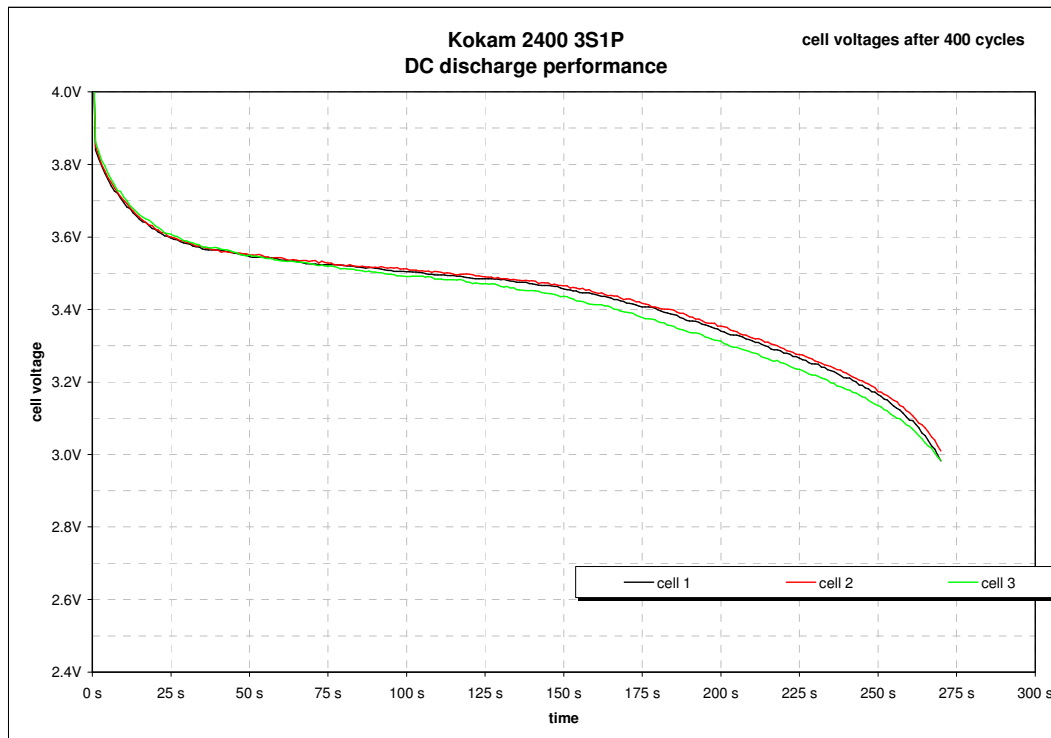


Fig.8, cell voltages after life test

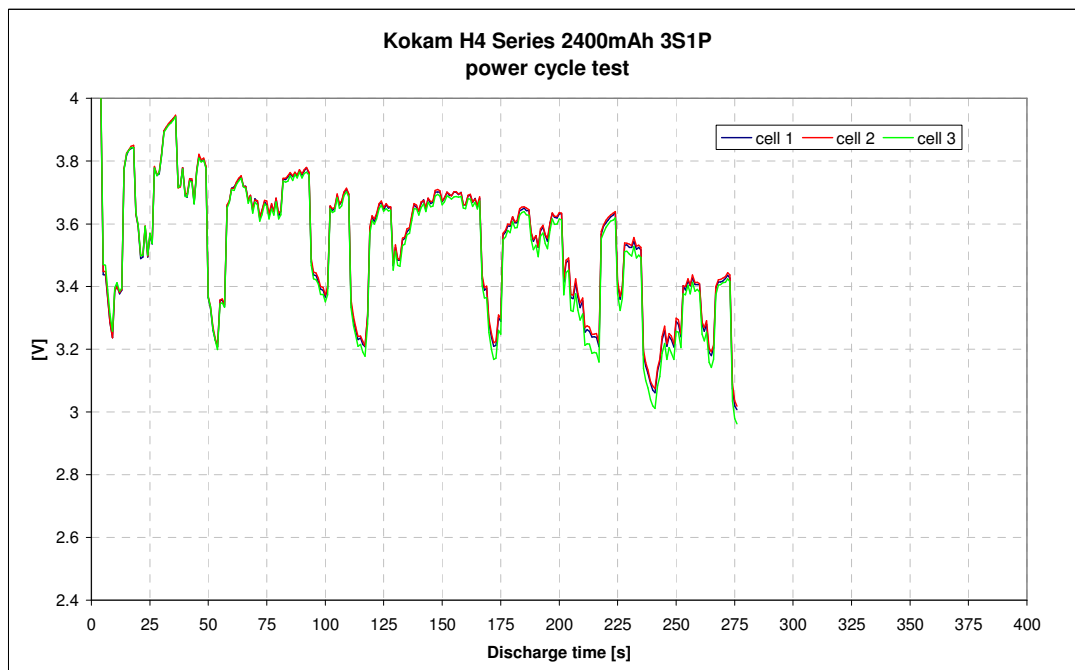


Fig. 9, cell voltages during the last cycle of life test

At the end of life test the discharge voltage difference between cell 3 and the other two cells was smaller than at the beginning.

Internal resistance

Internal resistance within one discharge cycle.

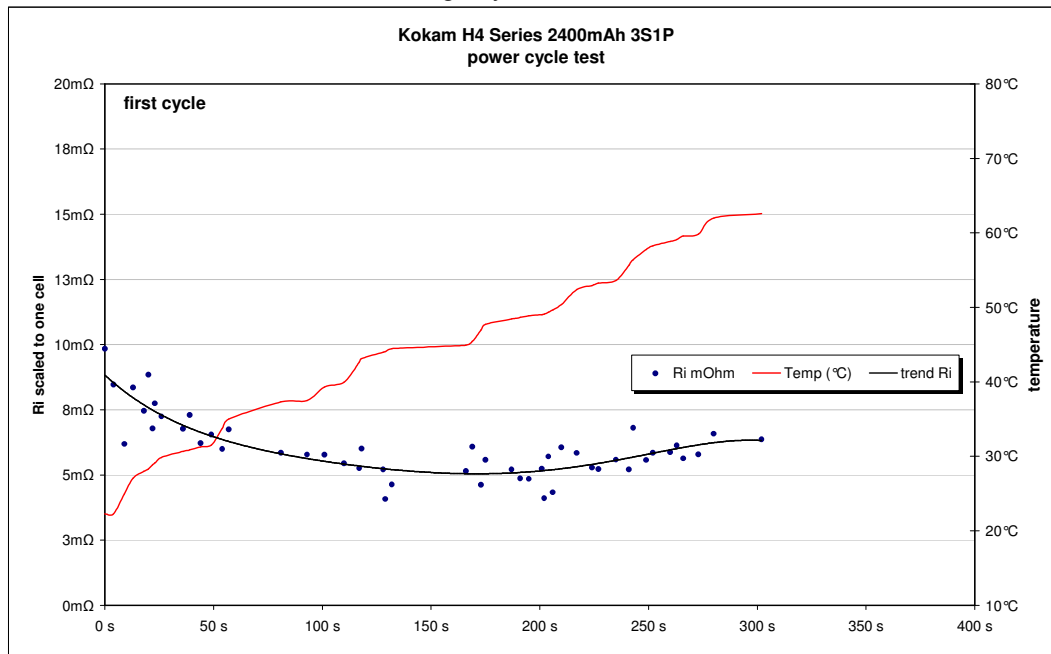


Fig. 10a Ri as a function of temperature and discharge time during the **first cycle** of life test

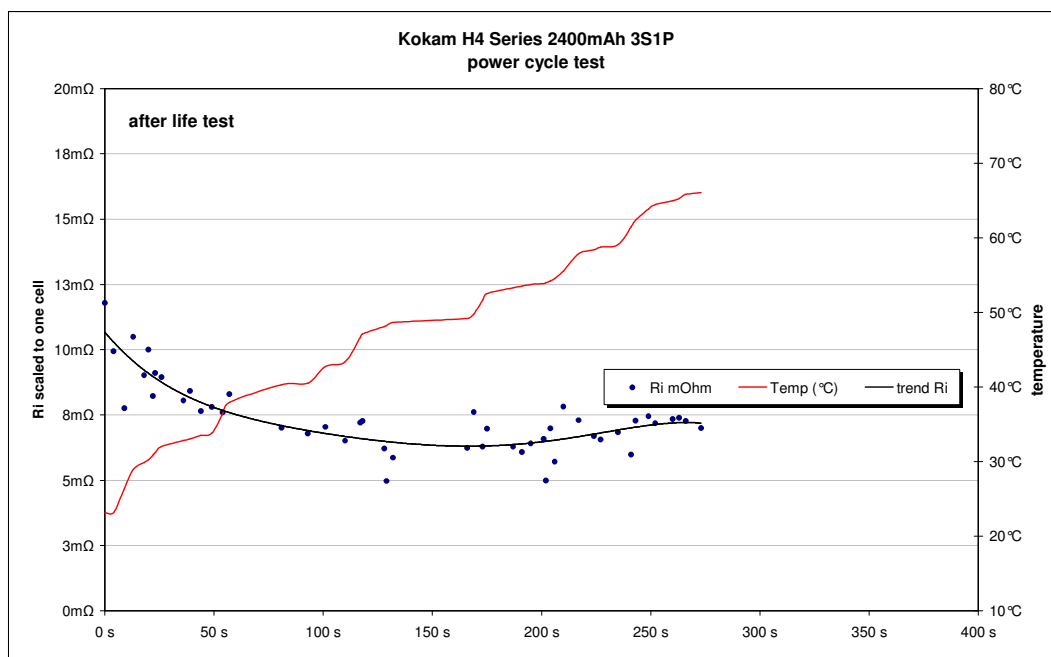


Fig. 10b the same as Fig.6a but **after 410 cycles** in life test

The temperature coefficient of Ri is moderate. The lowest Ri was observed in the middle of the discharge period at around 45°C.

Appendix A life test settings

Charge	0 - 410 cycles	
Recharge current	4.8A (2C)	
Recharge time	50 minutes	
Charge voltage	4.2 V/cell	
Discharge (-> Fig. A2/3)		
Peak current	72A (30C)	
Average current	25.3A	
RMS current	~ 33A	
Cut-off voltage	3V/cell	
Resulting DoD	> 95%	
Ambient conditions	Ta = 19 °C, cooling method: natural convection	
	No voltage balancing equipment was used	

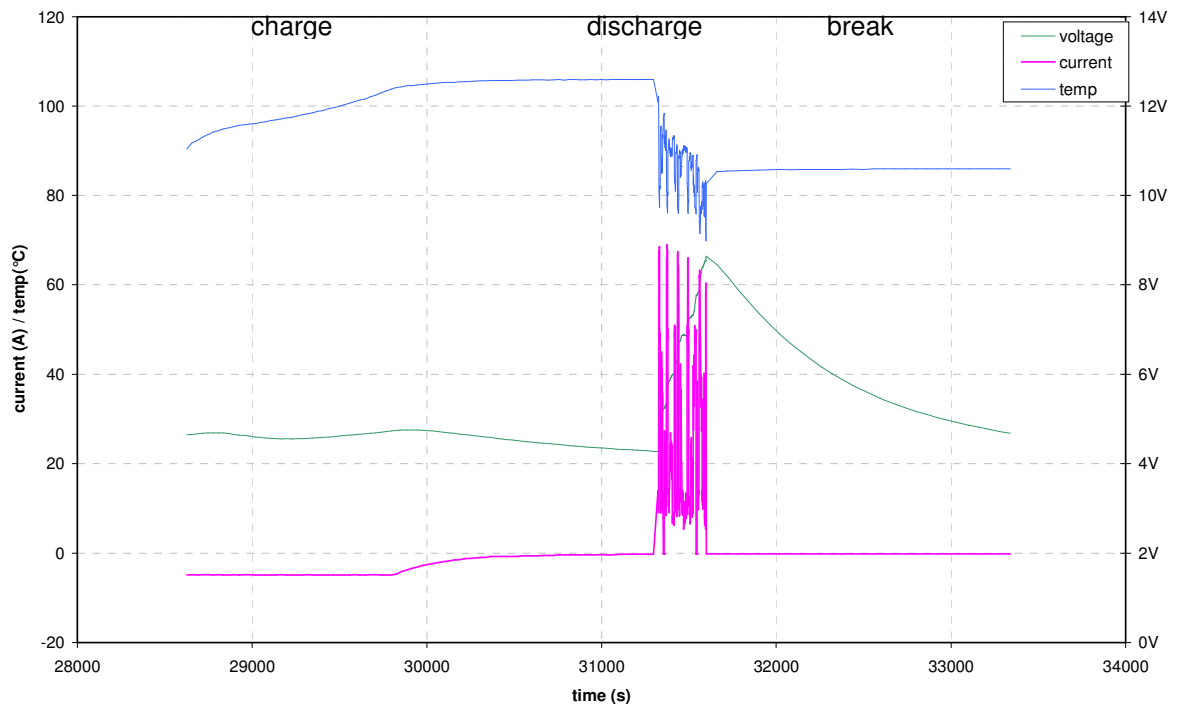


Fig. A1, a typical cycle of the life test

During the break time the battery temperature dropped below 30 °C.
 A small temperature rise during 2C recharge can be observed. The ambient temperature was between 19 and 20 °C for the whole test period.

Life test discharge current profile

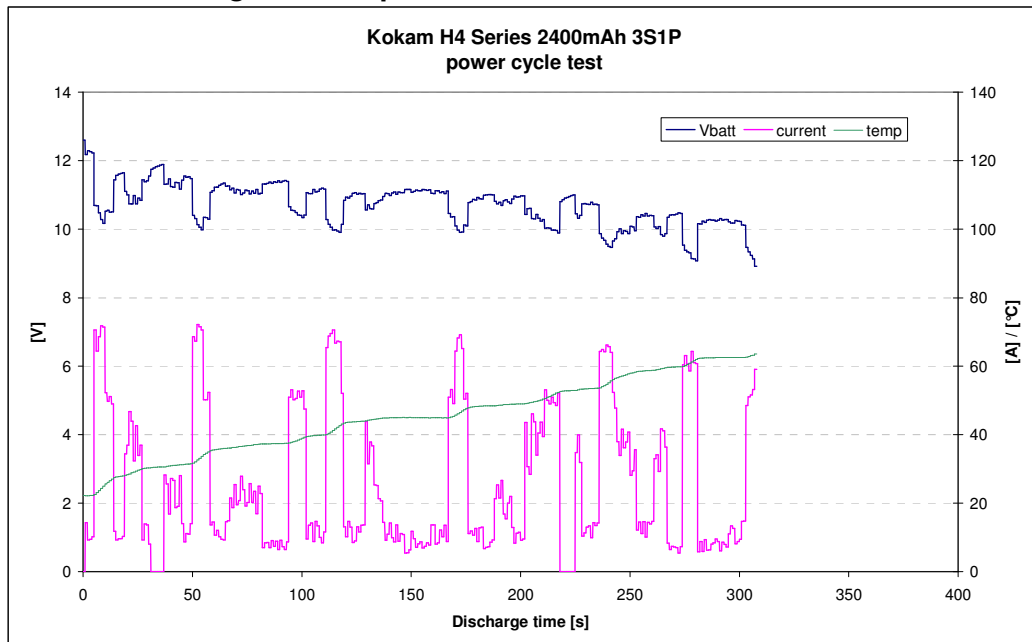


Fig. A2, voltage, current and temperature during discharge at the beginning of life test

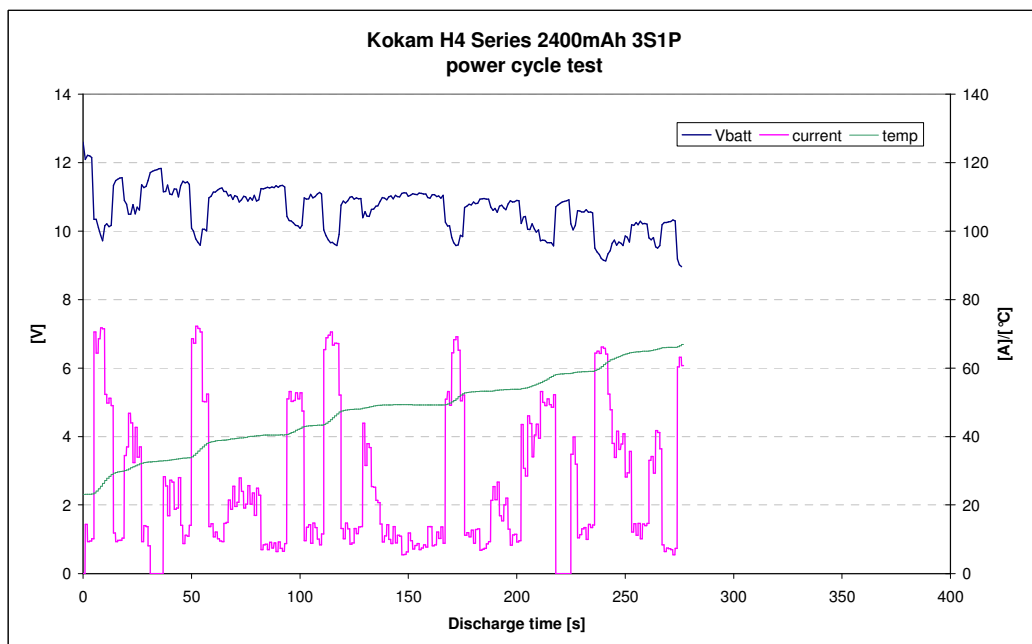


Fig. A3, a discharge cycle at the end of life test.

The same current profile was used for the whole life test. The resulting discharge time was around 300s with an average discharge current of 10.5C.