Technical Note *Cycle Life of LiPo Packs* N°:TN08004

Device under test

Kokam 3600 – 35C, 3S1P H5 series

Weight 356g incl. cable & connectors
Dimension 160x45x26mm

Test method
Test conditions

a) Evaluation of dc discharge properties: Idc = 6C/12C/20C/25C/30C

b) Life test according to PA06002-v4 with the following settings:
Icharge = 7.2A (2C), Vcharge =4.2V/cell,
Discharge: Ip = 126A (35C), Iaverage = 42A (8.5C), Vcutoff = 3V/cell
see appendix A for details

c) Intermediate capacity tests @ Idc = 43.2A, Icharge = 3.6A, Vcutoff = 3V/cell

Results overview

DC discharge properties (initial condition, Fig. 1**)**

discharge current	capacity [Ah]		discharge voltage Vm/cell		ΔT [K]
21.6A	3.43	100%	3.60	100%	26
43.2A	3.41	99%	3.51	98%	39
72A	3.34	97%	3.43	95%	50
108A	3.30	96%	3.29	91%	66

Energy density measured with 12C dc current: 101Wh/kg (initial value)

Life test, 350 cycles (Fig. 2-8)

	discharged capacity [Ah]	Vm [V/cell]	supplied energy [Wh]	Ri [mΩ/cell]	temperature rise ΔT [K]
new	3.32	3.46	34.3	3.0	46.9
150 cycles	3.25	3.43	33.5	3.5	45.9
350 cycles	2.85	3.35	29.4	3.8	43.6

Energy density under the life test conditions: 96Wh/kg (initial value)

Capacity check with **43A dc** (Fig. 3)

	12C capacity [Ah]		12C discharge voltage Vm/cell		ΔT [K]
before life test	3.41	100%	3.51	100%	39.3
after 90 cycles	3.34	98%	3.50	100%	39.9
after 180 cycles	3.26	96%	3.48	99%	42.4
after 350 cycles	3.24	95%	3.47	99%	42.2

Cell symmetry (Fig. 6 and 7)
The cells were well matched in terms of capacity and internal resistance. While the relative cell capacities remained constant, the discharge voltages of the individual cells drifted somewhat apart during the test.

Conclusions & Comments

- The Kokam 3600mAh-35C cells are robust and well suited for high current discharge pulses (35C or even higher). They can also handle dc currents up to 90A (25C) without forced cooling. Temperature rise and internal resistance are quite low.
- Even under hard cycle test conditions a low deterioration of capacity and internal resistance was observed. This suggests a cycle life of several hundred cycles. However, for very high discharge currents (>30C) the limiting factor for the useful life is the increase of the internal resistance which may cause an intolerable voltage drop. The limit depends on the specific application and since the internal resistance is also a function of temperature (pre-heating, cooling etc.) a general statement about life expectation for such applications cannot be made here.
- The battery came with well matched cells, the observed relative drift during the cycle test is uncritical.
- Compared to the Kokam 30C series the energy density is slightly lower.

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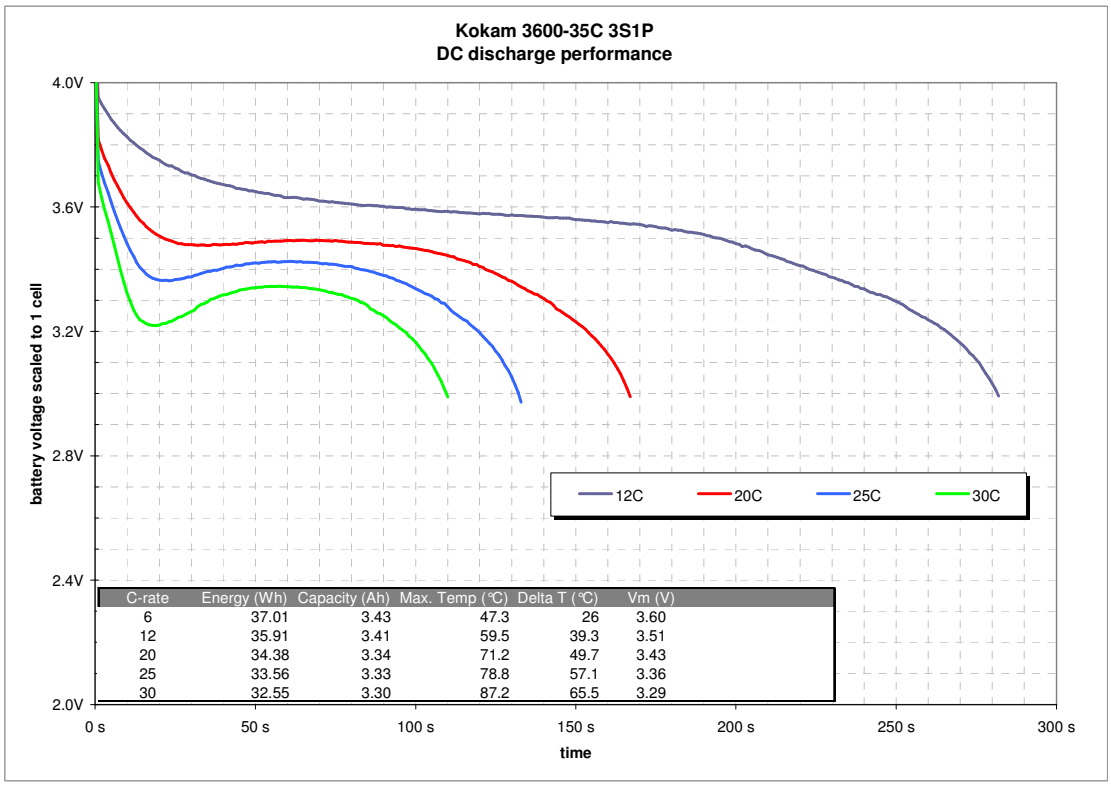
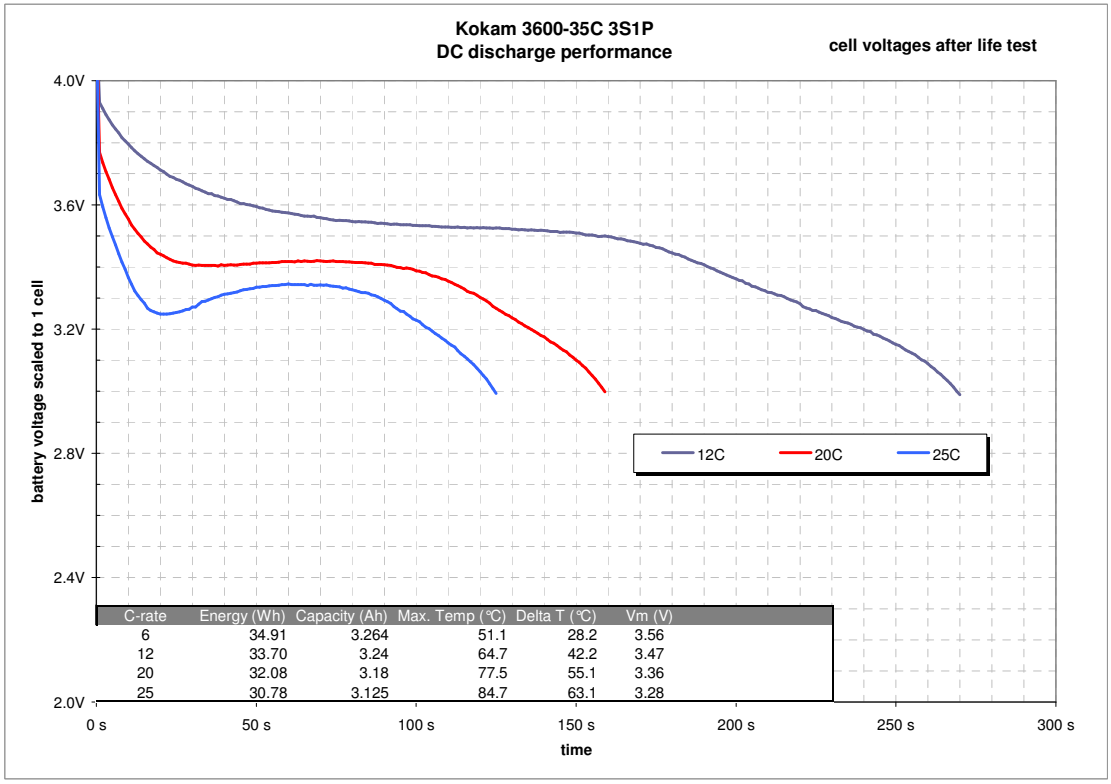
DC discharge performance



C-rate	Energy (Wh)	Capacity (Ah)	Max. Temp (°C)	Delta T (°C)	Vm (V)
6	37.01	3.43	47.3	26	3.60
12	35.91	3.41	59.5	39.3	3.51
20	34.38	3.34	71.2	49.7	3.43
25	33.56	3.33	78.8	57.1	3.36
30	32.55	3.30	87.2	65.5	3.29

Fig. 1a, discharge performance before life test



C-rate	Energy (Wh)	Capacity (Ah)	Max. Temp (°C)	Delta T (°C)	Vm (V)
6	34.91	3.264	51.1	28.2	3.56
12	33.70	3.24	64.7	42.2	3.47
20	32.08	3.18	77.5	55.1	3.36
25	30.78	3.125	84.7	63.1	3.28

Fig. 1b, discharge performance after life test (359 cycles)
The loss of capacity after all the tests was around 8% while the temperature rise increased by 10% for discharge currents of 40A and up. The 108A (30C) discharge was not repeated after life test (temperature rise!).

Life test

For the life test a current pulse pattern with a peak current of 126A and an average of 37A was used (refer to appendix A). The selected pulse pattern resulted in almost 100% DoD at the beginning. During cycle test DoD gradually reduced to 88%. Under the high current discharge pulses and due to the increased inner resistance the battery voltage dropped below 3V/cell before it was completely discharged.

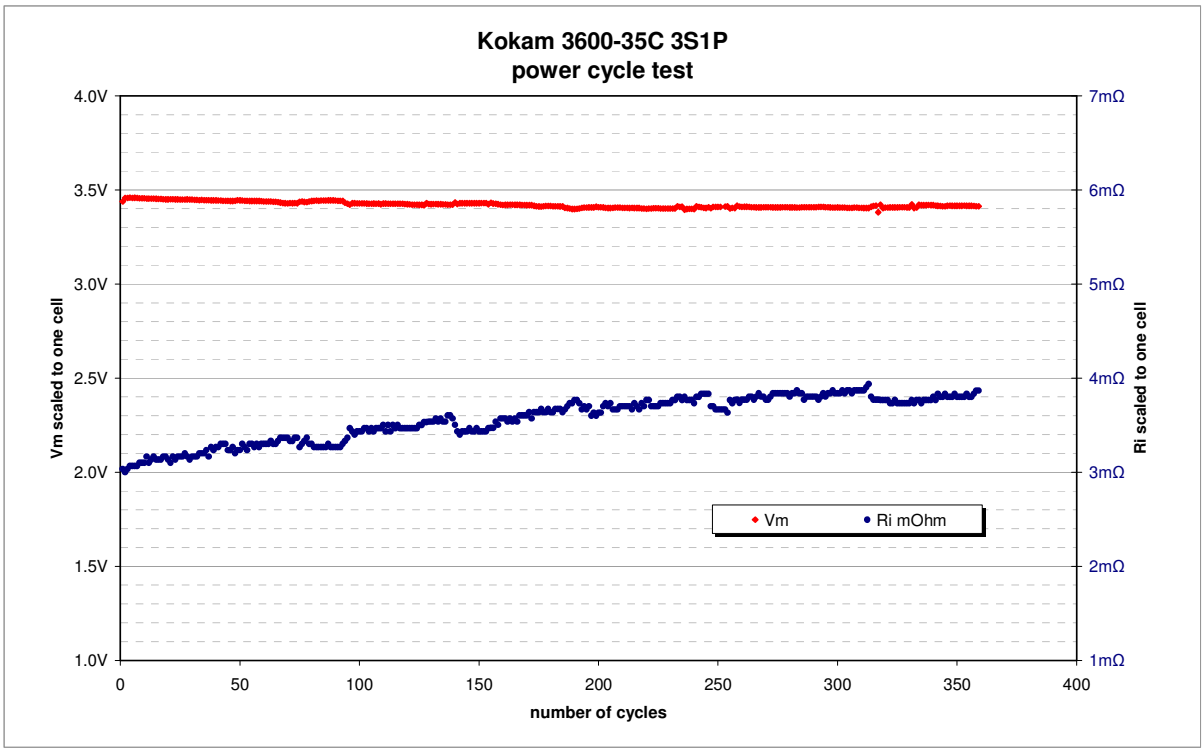


Fig. 2, discharge voltage Vm and internal resistance Ri vs number of cycles

The displayed Ri values are mean averages which were recorded between 160s and 200s after beginning of discharge. The small variations came from ambient temperatures fluctuations(18 – 21℃).

During life test Ri increased from 3mΩ to almost 4mΩ which is an increase of 10% per 100 cycles.

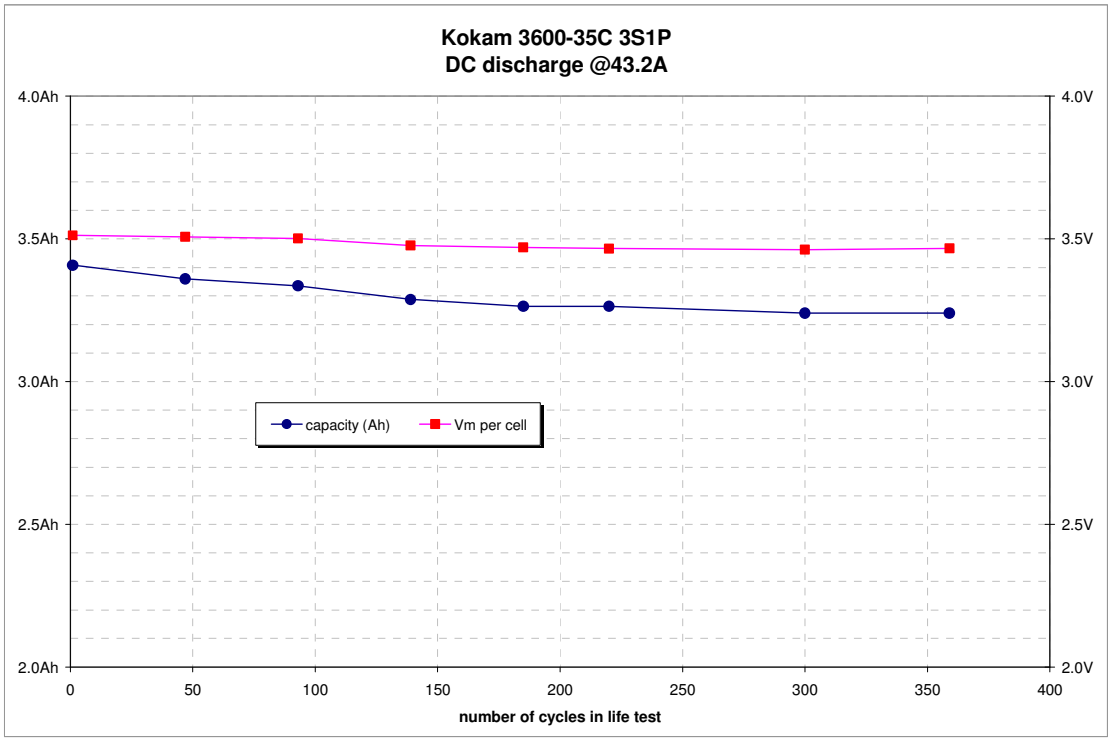


Fig. 3, Trend of capacity vs. number of cycles. The capacity was measured @ 43.2Adc and Vcutoff = 3V/cell

The capacity dropped about 2.5% during the first 100cycles. The total capacity loss after cycle life test was about 7%.

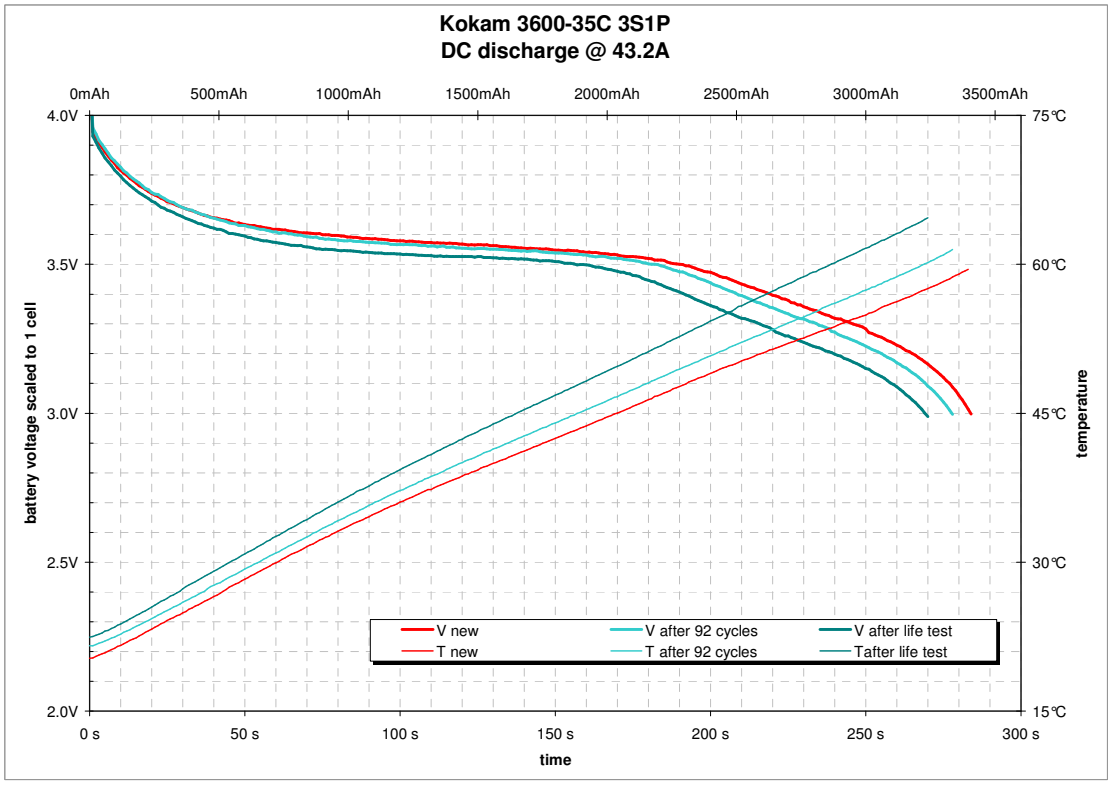


Fig. 4, Comparison of discharge voltage curves and temperatures @ 43.2A (12C)

Cell symmetry

Before life test

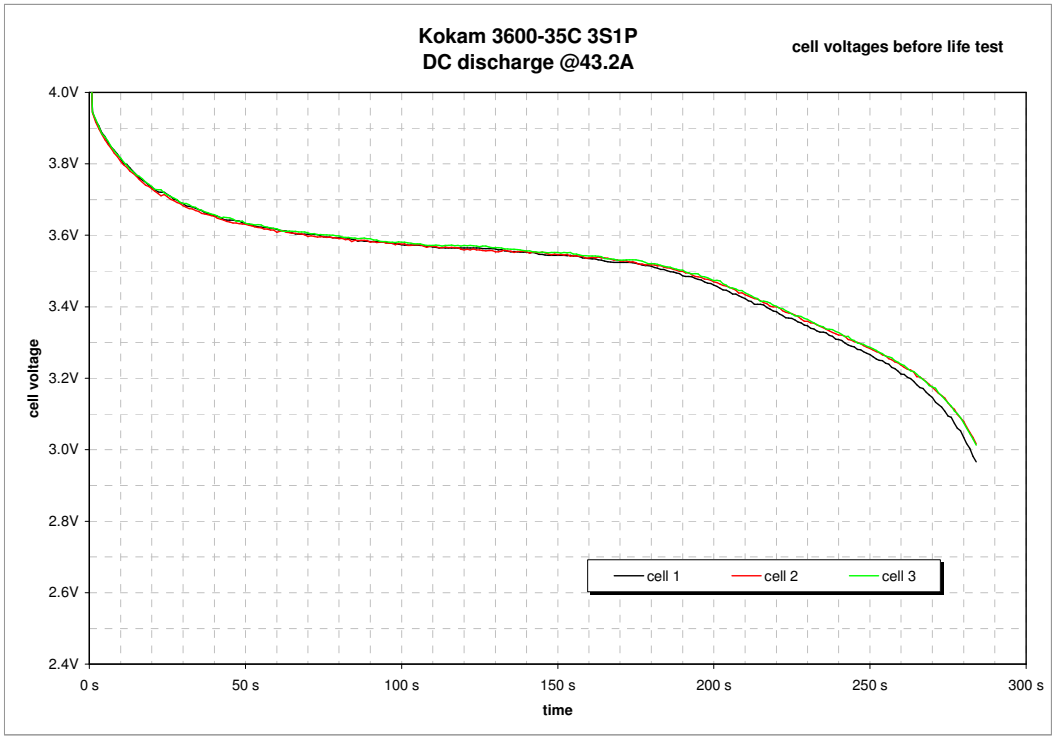


Fig. 6a, Cell voltages before life test under 43.2Adc discharge

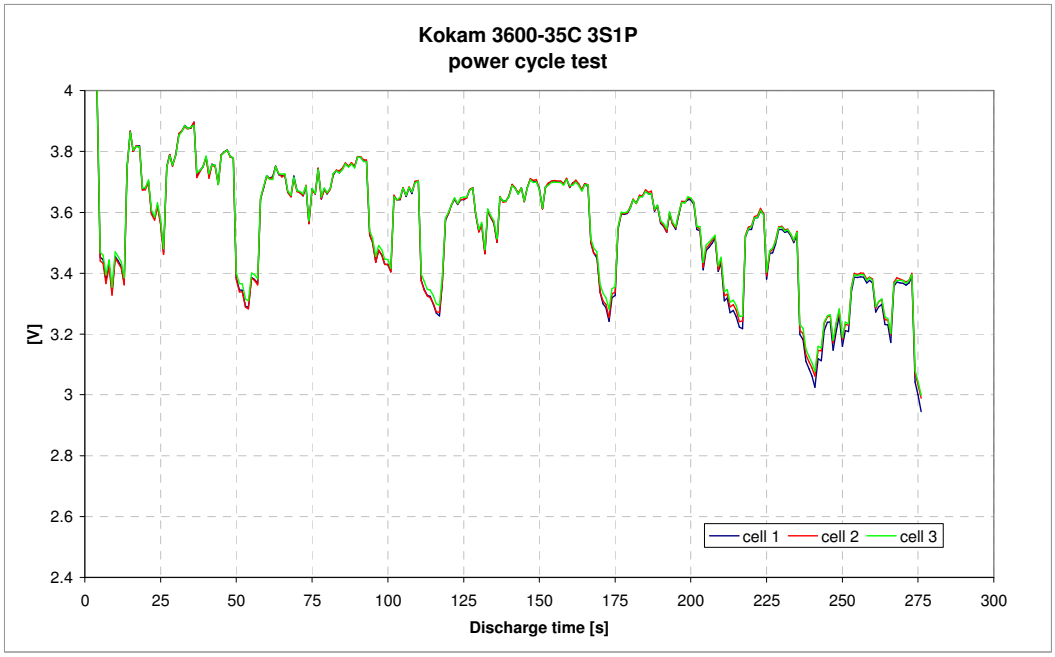


Fig. 6b, cell voltages during the first cycle of life test

After life test

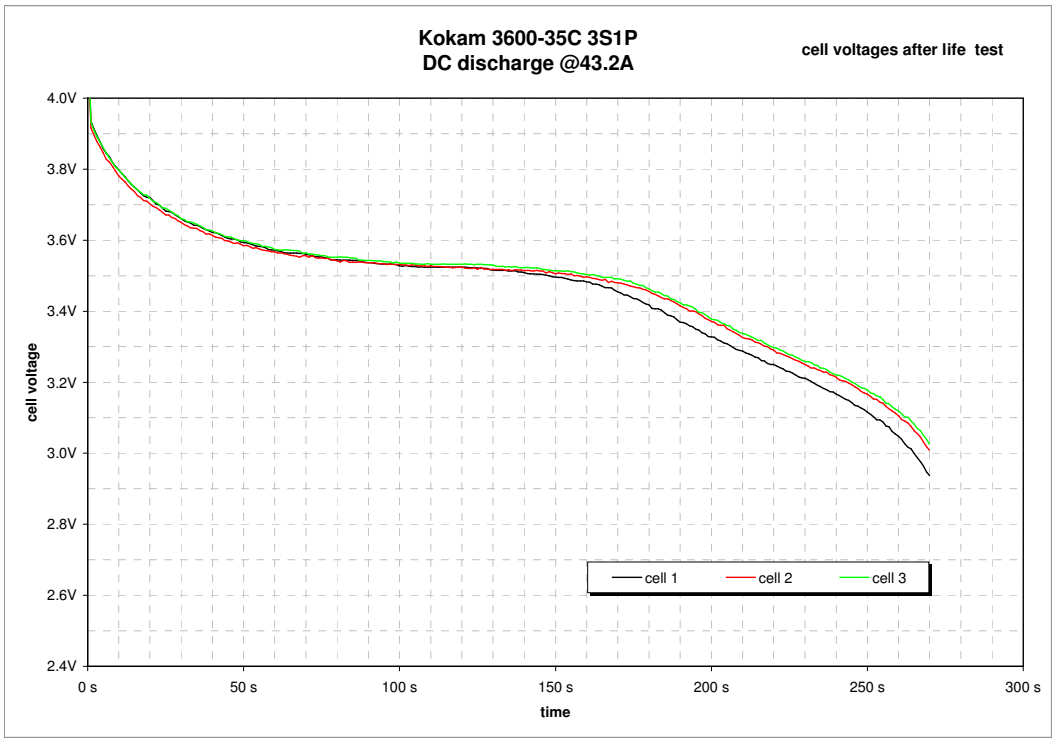


Fig. 7a, Cell voltages after life test (350 cycles)

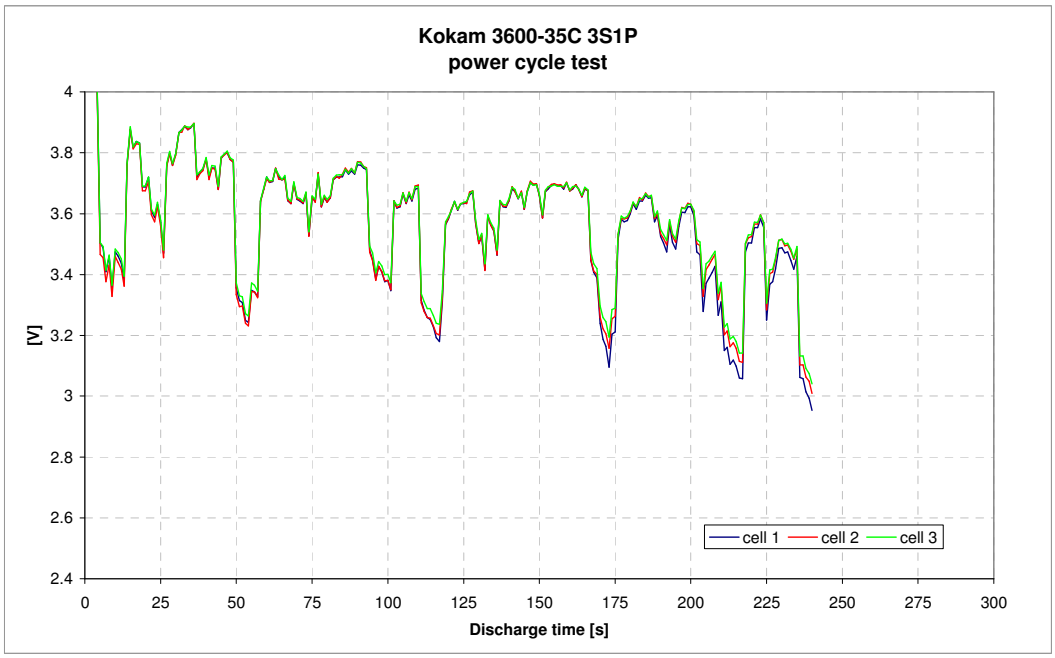


Fig. 7b, cell voltages in the last cycle of life test

The 3 cells of the tested battery were well matched for capacity and discharge voltage. After cycle test a non-uniform discharge voltage of the individual cells was observed. However, the behaviour is not considered as critical because the individual cell capacities did not differ significantly.

Internal resistance

Internal resistance within one discharge cycle.

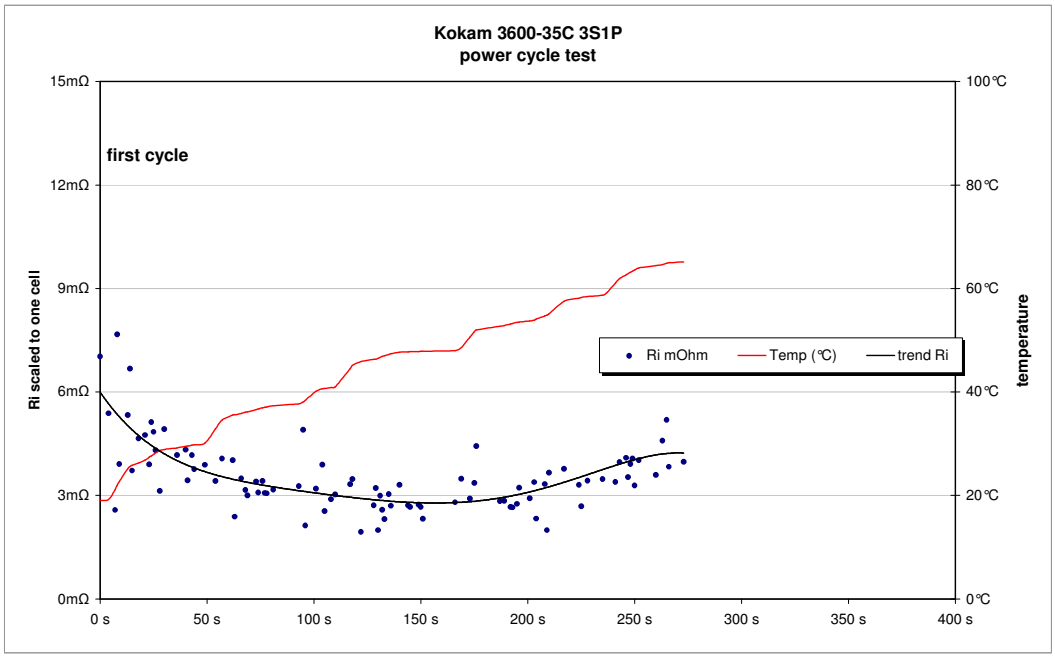


Fig. 8a Ri as a function of temperature and discharge time during the **first cycle** of life test

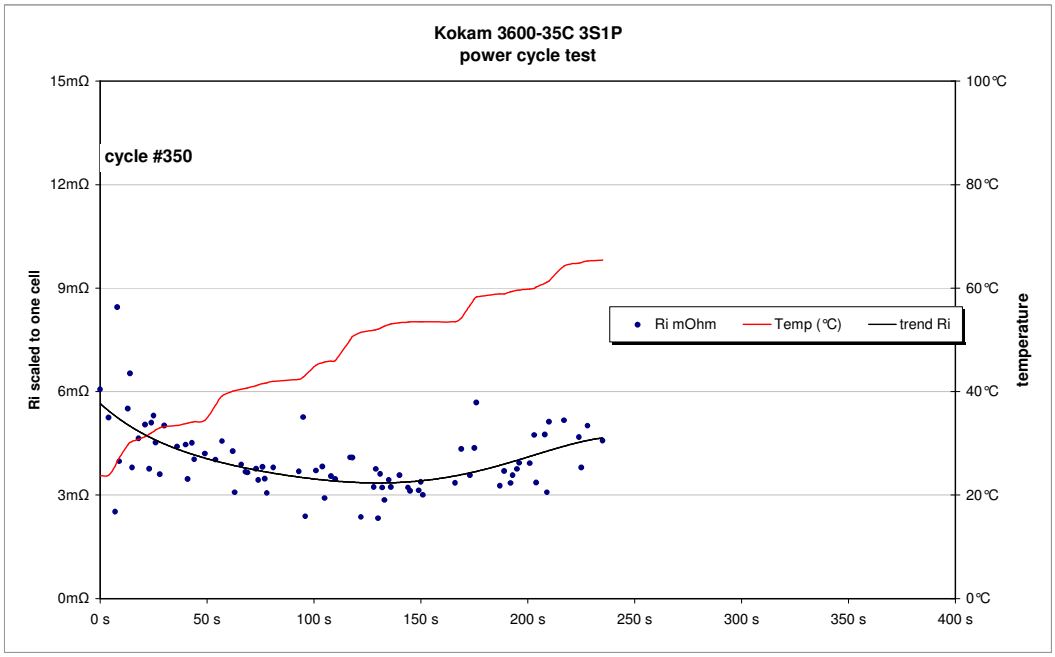


Fig. 8b the same as Fig.8a but **after 350 test cycles**

The temperature coefficient of Ri is moderate and a low Ri is already reached at temperatures of 35℃ and higher.

Appendix A life test settings

Charge	**0-350 cycles**	
Recharge current	7.2A (2C)	
Recharge time	50 minutes	
Charge voltage	4.2 V/cell	
Discharge (-> Fig. A2/3)		
Peak current	126A (35C)	
Average current	37A	
RMS current	~ 46A	
Cut-off voltage	3V/cell	
Resulting DoD	~ 98% at the beginning and ~ 88% at the end of the test	
Ambient conditions	Ta = 18-21 ℃, cooling method: natural convection	
	No voltage balancing equipment was used for the test	

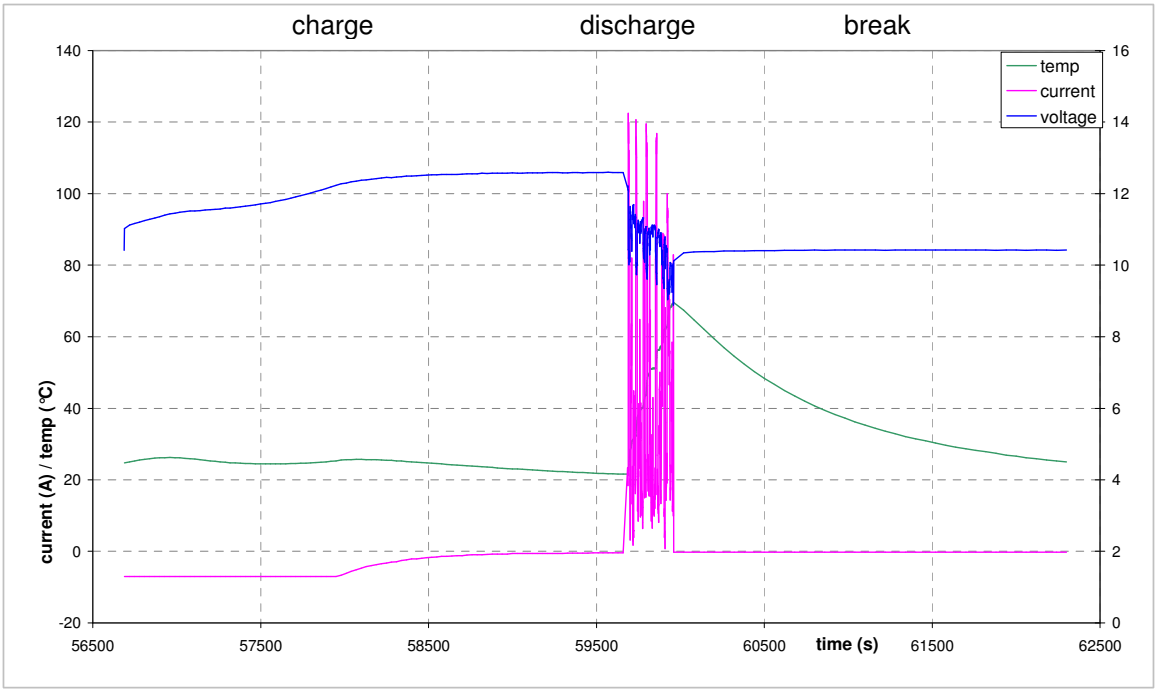


Fig. A1, a typical life test cycle

During the 40 minutes break time the battery temperature dropped down to about 25℃.
The charge current didn't cause any considerable temperature rise.

Discharge current profile

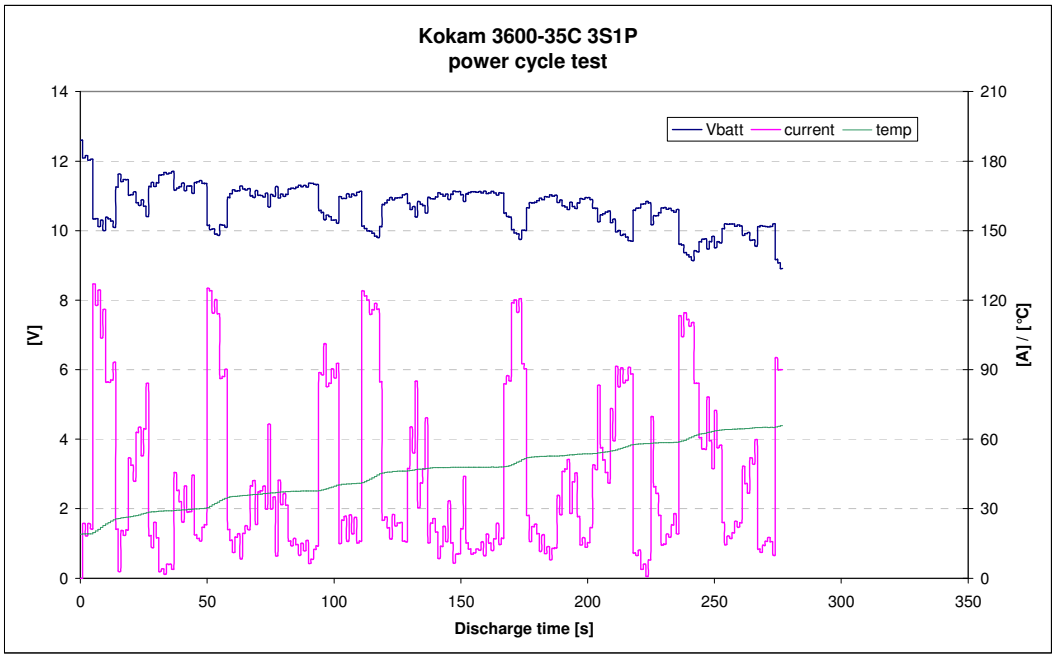


Fig. A2, discharge cycle at the beginning of life test

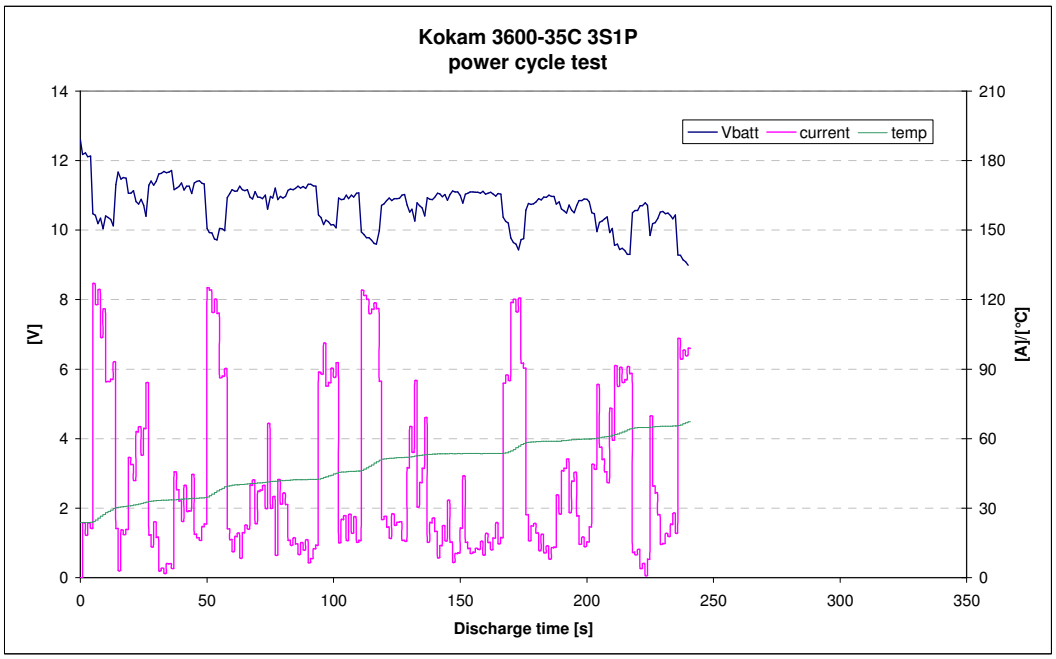


Fig. A3, discharge cycle towards the end of life test.

For the whole life test the current profile remained unchanged. The resulting discharge time was between 240s to 280s.