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LITHIUM-ION BATTERY LIFE

Causes of Lithium-Ion Battery Aging

As any battery, the lithium-ion battery works by means of movement of ions between positive and negative electrodes. Cycling, elevated temperature and aging decrease the battery life. Evaluating battery life on counting cycles is not conclusive because a discharge may vary in depth and there are no clearly defined standards of what constitutes a cycle.

The performance of a battery is measured in capacity. Internal resistance and self-discharge also play roles, but these are less significant in predicting the end of Li-ion battery life. In this article, useful cycle life is assumed before the initial battery capacity drops to below 70%.

Major Contributors to Aging of Lithium-Ion Cells

- Number of charge / discharge cycles (Chart 1)
- The depth of discharge (DoD). The smaller the discharge (low DoD), the longer the battery will last (Table 1)
- Storage temperature and SoC (Table 2)
- Charge level. Higher charge voltage boosts capacity and lowers cycle life (Table 3 and Figure 2)
- Dynamic Cycling (Figure 3)

Chart 1: *Capacity drop as part of cycling*

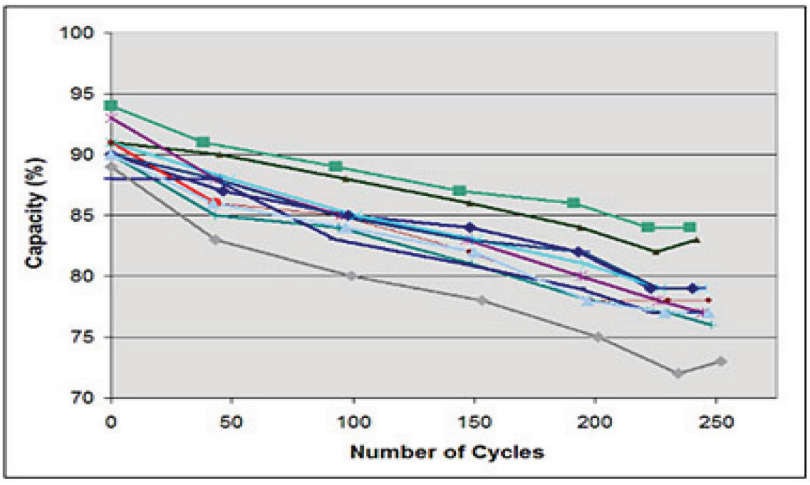

Chart 1 illustrates the capacity drop over 250 cycles of lithium polymer cells. The cells were cycled using 1°C charge and 1°C discharge rates in room temperature. The cells during each cycle were charged to ~4.25V and discharged to 3.0V.

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Table 1: *Charge / discharge cycles of Li-ion at various DoD levels*

Depth of discharge	Discharge cycles
100% DoD	~300
80% DoD	~400
60% DoD	~600
40% DoD	~1,500
20% DoD	~1,500
10% DoD	~10,000

Table 2: *Capacity loss as a function of temperature and SoC*

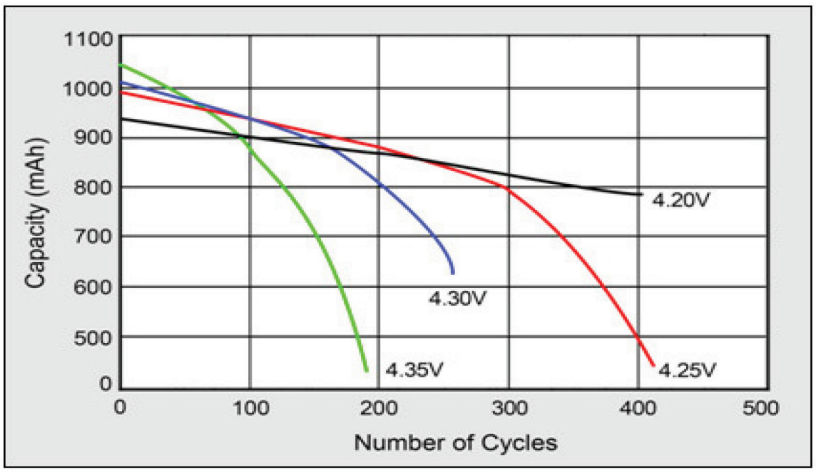
Temperature	40% charge	100% charge
0°C	98%	94%
25°C	96%	80%
40°C	85%	65%
60°C	75%	60% (after 3 months)

Table 3: *Capacity and discharge cycles versus charge levels*

Charge Level (V/Cell)	Discharge cycles	Available stored energy
4.30	150–250	110–115%
4.25	200–350	105–110%
4.20	300–500	100%
4.15	400–700	90–95%
4.10	600–1,000	85–90%
4.05	850–1,500	80–85%
4.00	1,200–2,000	70–75%
3.90	2,400–4,000	60–65%

Reduction in peak charge voltage of 0.10V/cell can double the cycle life. A lower peak charge voltage reduces the capacity the battery stores. About every 70mV reduction in charge voltage lowers the overall capacity by 10 percent. In terms of longevity, the optimal charge voltage is ~3.9V/cell. This voltage level eliminates all voltage-related stresses; going lower does not produce further benefits.

Figure 2: *Cycle count versus charge voltage*



***Note:** Partial charging reduces overall energy content. Higher charge voltage increases capacity; high charge voltage levels shorten service life and compromise safety.

Figure 3: *Capacity loss versus % charge / % discharge dynamic cycling*

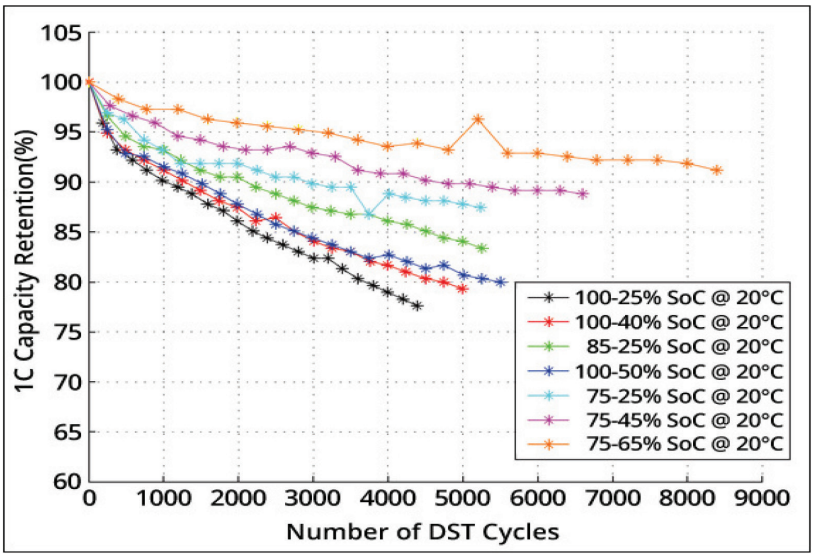


Figure 3 illustrates dynamic stress tests (DST) reflecting capacity loss when cycling Li-ion at various charge and discharge limits. 75–65% SoC provides longest cycle life, 100–25% SoC provides long runtime, makes best use of battery, yet reduces battery life. Mid-range of 85-25% percent reduces the energy to 60%.

Conclusion

Environmental conditions, not cycling alone, dominate the longevity of lithium-ion batteries. The worst situation is keeping a fully charged battery at elevated temperatures. Keeping battery at high temperature and high state-of-charge for an extended period of time is more stressful than any cycling. Battery packs do not die suddenly, the runtime slowly shortens as the capacity fades. Lower charge voltages prolong battery life. A partial discharge reduces stress and prolongs battery life, so does a partial charge. Operating at elevated temperature and high currents also adversely affects cycle life.

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