Physical SEI Growth Model Meets Aging Experiments of LFP/Graphite Cells Across Various Cycling Conditions

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Lithium iron phosphate (LFP)–based lithium-ion batteries (LIBs) are a cost-effective and safe technology widely used in applications where long lifetime is of superior importance. At moderate operating temperatures, degradation in LFP cells is predominantly governed by the growth of the solid–electrolyte interphase (SEI) at the graphite anode, which leads to continuous capacity fade. Despite extensive experimental and modeling efforts, physically based lifetime models that consistently account for material properties and operating conditions remain limited.

In this work, we combine systematic aging experiments with a physically derived SEI growth model to investigate degradation mechanisms in LFP/graphite lithium-ion batteries. Aging experiments were performed using a broad range of cell specifications, including different artificial graphite materials, electrolyte salts, additives, temperatures, and cycling protocols [1,2]. This comprehensive experimental dataset enables a detailed assessment of the influence of both material selection and operating conditions on the long-term degradation behavior.

To describe the experimental observations, we employ a physical SEI growth model based on electron diffusion through the SEI layer [3,4]. In this framework, electron diffusion across the SEI determines the rate of SEI growth, resulting in a characteristic square-root-of-time profile and the observed dependence of capacity fade on the state of charge via the intrinsic dependence on the anode potential. The SEI model is consistently parametrized with respect to the cell specifications, allowing to disentangle the effects of material choices, such as type of artificial graphite, electrolyte salt, and additives. This enables a unified description of SEI growth across different cell configurations and cycling protocols without repeated re-fitting. Once parametrized, the model accurately reproduces experimental degradation trends for a variety of cell configurations and enables reliable predictions for intermediate temperatures and arbitrary cycling protocols. Notably, both the square-root time dependence and the dependence on the cycling protocol do not result from additional fit parameters but emerge naturally from the underlying electron diffusion mechanism. As such, the model represents a powerful tool for degradation predictions and provides guidelines for the lifetime optimization of lithium-ion batteries. More generally, this approach can be extended to different anode or cathode materials, particularly silicon-based anodes, where mechanical effects due to large volume changes strongly influence SEI evolution and the anode potential [5].

In conclusion, we demonstrate that our physical SEI growth model based on electron diffusion can quantitatively describe degradation in LFP/graphite cells across a wide range of material specifications and operating conditions. Furthermore, the model enables predictive lifetime assessments under realistic operating scenarios and provides strategies to decelerate degradation processes.

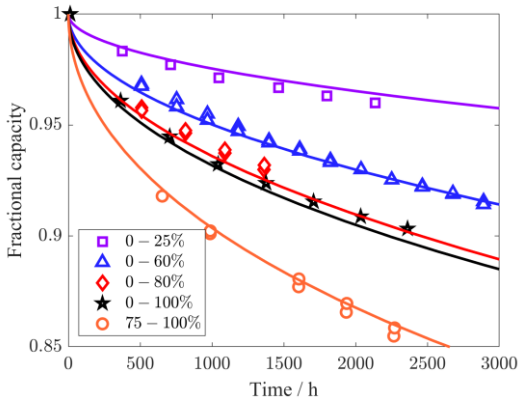

Fig. 1: Fractional capacity retention for LFP/graphite cells cycled in different SoC regions

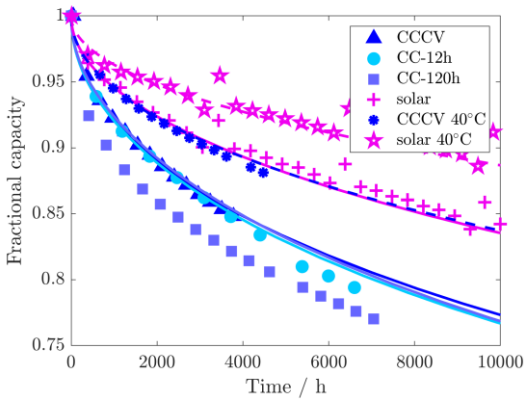

Fig. 2: Fractional capacity retention for LFP/graphite cells cycled with different protocols

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