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A Fatigue Analysis for Lithium-ion Batteries

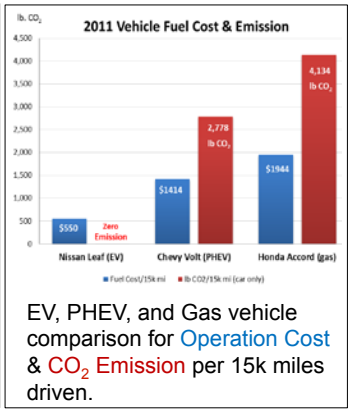
Michael A. Stamps and Hsiao-Ying Shadow Huang
Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, NC

Introduction and Background

Energy Storage Need

- Batteries provide the vital storage link between energy generation and consumption around the world.
- Energy demand is increasing, thus new generation facilities are being built and require large scale batteries to store energy for future transmission or backup power.
- Oil prices and CO_2 emissions are also increasing, driving the need for transportation alternatives (EV and PHEV).

World oil consumption and price projected to rise at a relatively constant rate [1].



EV, PHEV, and Gas vehicle comparison for Operation Cost & CO_2 Emission per 15k miles driven.

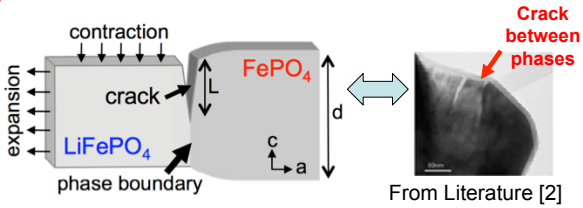
Applications

Objective

As it is known batteries experience capacity loss (power loss) over time as the electrode materials degrade, this research investigates the effects of cycling induced stresses and fatigue on $LiFePO_4$ cathode (positive electrode) particles to elucidate an understanding for crack propagation and fracture.

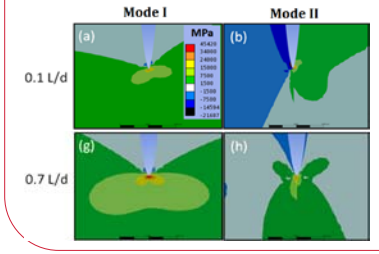
Simulation Method and Results for $LiFePO_4$

Simulation Set-Up for 2-Phase interface



From Literature [2]

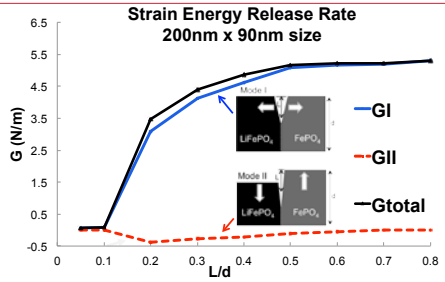
Mode Dependent Stresses



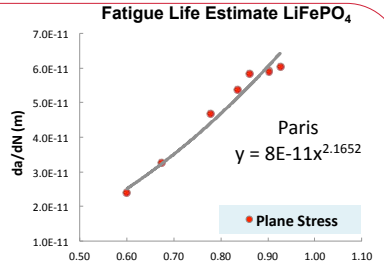
Mode I dominance increases as the crack grows.

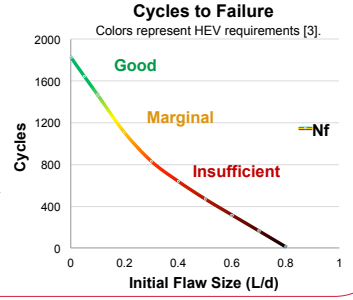
Fracture and Fatigue Analysis

- Choose $LiFePO_4$ due to long cycle life (~2000 cycles), wide op. temps. (-20 to 60°C) and superior thermal stability (safe, incombustible cells).
- Varying sized particles with varied initial crack sizes (nm scale) are analyzed via fracture mechanics.
- Plane Stress, plate-like particles are used with loading according to misfit strains (observed during lithium insertion, $FePO_4 \rightarrow LiFePO_4$).
- Mode dependent stresses , Strain Energy Release Rates (G), and Stress Intensity Factors (K) are calculated using ANSYS software.



- G is the crack driving force.
- An Energy Approach is applied to calculate da/dN and create a fatigue life estimate fit to the Paris law.
- If $G > 2\Upsilon$, propagation may occur. Υ=particle surface energy on the crack faces
- Cycles to failure (Nf) can be calculated iteratively based on initial crack size.





Conclusion

- Crack propagation and fracture is highly dependent on mode (I or II), misfit %, and particle size.
- Smaller particles show reduced G (crack driving force). Max is always near L/d=0.5.
- Fatigue cycle life estimate of 1800 cycles is fairly consistent with manuf. reported value (2000).
- Understanding what happens at the nm-scale provides insight into what bulk-scale modifications could be made to improve the performance and life of batteries.

Bibliography

[1] Data for this figure compile from: U.S. Energy Information Administration (EIA), 2011.
[2] Gabrisch et al, *Electrochemical and Solid State Letters, 11*(3), A25-A29, 2008.
[3] United States Council for Automative Research LLC (USCAR), "U.S. Advanced Battery Consortium: Energy Storage System Goals", 2012.

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