Particle-Particle Interaction within the Electrodes of Lithium-Ion Batteries

Cong Zhang, A.T. Conlisk
Center for Automotive Research,
Department of Mechanical and
Aerospace Engineering, Ohio State University
930 Kinnear Road, Columbus, OH 43212

Understanding the consequences of mechanical stresses in lithium-ion batteries is particularly important for improving the cycle life of next generation Li-alloy active materials such as Li-Si and Li-Sn [1] as well as ensuring effective liquid phase transport to all regions of the electrodes [2]. The cycle life of these electrodes is poor with crack formation leading to loss of active material being cited as the source of poor cycle life [3]. The kinds of mechanical stresses examined so far in the literature are mostly the intercalation stresses [4, 5], which are induced during battery operation as a result of lithium concentration gradient within the active material particles.

The particles within lithium-ion battery cells can undergo relative motion with relative velocities of different magnitude. The small values of the velocities can be a result of gradual morphology change of the particles during battery operation [6], while the large values of the velocities can be a result of an instantaneous impulsive motion triggered by a sudden switch-on of battery charging or discharging or local mechanical failure. The electrolyte solution inside the pores of the active materials acts as a resistance to the relative motion. However, the effect of the electrolyte solution is not conventionally considered. The main objective of this research is to propose another source of mechanical stresses besides the intercalation stresses as a consequence of the solid particle-particle interaction through the liquid electrolyte solution.

The electrolyte solution within the pores of the active material, in the form of a thin film between particles within the active material, is the medium through which the particles interact with each other. The relative motion of the particles: horizontally sliding motion and vertically squeezing motion (Figure 1), induce a pressure as large as the intercalation stress induced during battery charging and discharging. The calculation is based on lubrication approximation of fluid mechanics. Detailed results for the pressure field between the particles indicate the role of electrolyte cannot be ignored.

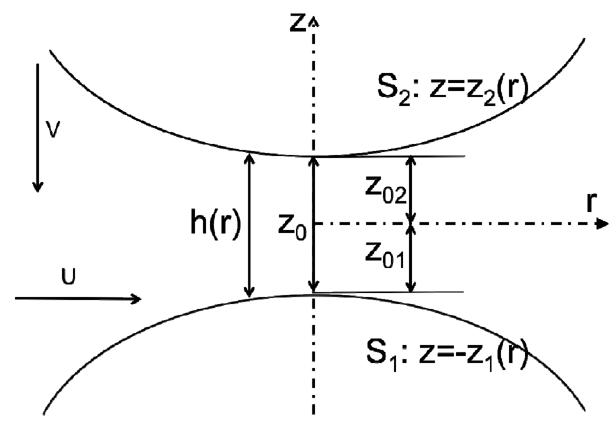

Figure 1. The schematic of the model domain of two scenarios: (a) two spherical particles undergoing horizontally sliding relative motion with the upper particle stationary and the lower particle moving with a constant velocity U and (b) two spherical particles undergoing vertically squeezing relative motion with the upper particle moving with a constant velocity V and the lower particle stationary.

ACKNOWLEDGMENTS
The authors graciously acknowledge financial support from Graduate Automotive Technology Education Industry Fellowship Fund.

REFERENCES

1. W.J. Zhang, *J. Power Sources*, **196**, 13 (2011).
2. R. Chandrasekaran and T. Fuller, *J. Electrochem. Soc.*, **158** (8), A859 (2011).
3. U. Kasavajjula, C. Wang, A. J. Appleby, *J. Power Sources*, **163**, 1003 (2007).
4. Y.T. Cheng and M. Verbrugge, *J. Electrochem. Soc.*, **157** (4), A508 (2010).
5. M. W. Verbrugge and Y. T. Cheng, *ECS Trans.*, **16** (13), 127 (2008).
6. S. C. Nagpure, B. Bhushan, S. Babu, and G. Rizzoni, *Scripta Materialia*, **60** (11), 933 (2009).