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STRUCTURAL HOMOGENIZATION IN ENERGY STORAGE SYSTEMS

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Structural analysis of battery packs consisting of hundreds of lithium-ion cells is a computationally challenging multiscale problem. In case of structural impact macro analysis, it is important to be able to reduce model's complexity through structural homogenization of each cell's jellyroll structure. The jellyroll consists of hundreds of anode, cathode and separator micron-level thick layers wrapped around a center pin. The layers are not bonded together and separator material is much softer than the electrodes, which makes it very difficult to model unless the jellyroll is treated as a homogenized structure.

Several methods of modeling jellyroll have been reported in the literature. One way to treat the material behavior of the roll in is by representing it as a laminated composite structure. Chatiri et al. assessed thick layered shell formulation in composite applications in order to decrease solution time but still maintain an acceptable accuracy [1]. However, layered thick shell formulation is not suitable for models with high aspect ratio elements and models including soft materials such as a polymer separator. Classical laminated shell theory can also be used to find homogenized material response of the jellyroll using a multilinear interpolation of strain-stress curve [2]. However, results obtained using laminated shell theory tend to be much stiffer than experimentally observed jellyroll's structural response.

In this work, we have analyzed two methods of obtaining accurate homogenized properties of the jellyroll in lateral (radial) direction. The first method was based on uniaxial tests using flattened jellyroll specimens, while in the second approach stress-strain relation was estimated using a combination of experimental/analytical methods based on the virtual work principle [3]. The experimentally obtained stress-strain curves were incorporated into explicit finite element models used to simulate crushing cell impact placed between two flat plates. In order to verify the developed FE models, experiments were conducted on cylindrical cells using custom designed drop test apparatus.

Several cylindrical cells were tested using a flat rigid drop cart in a custom-built drop test apparatus. Two proposed homogenization methods for the jellyroll in a cylindrical lithium-ion battery cell produced similar mechanical response of the homogenized material for relatively small strains. However, for the strains larger than 0.1 the difference between two material models would gradually increase to be as large as 25% for strains of 0.3. Based on the results of homogenization, the material model utilizing crushable foam constitutive behavior was then developed for the finite element impact simulations in LS-DYNA. Experimental results showed a very good agreement with simulations based on the direct homogenization method (see Figure 1), thus validating proposed approach and giving us confidence in moving forward with the impact simulations of an entire battery pack.

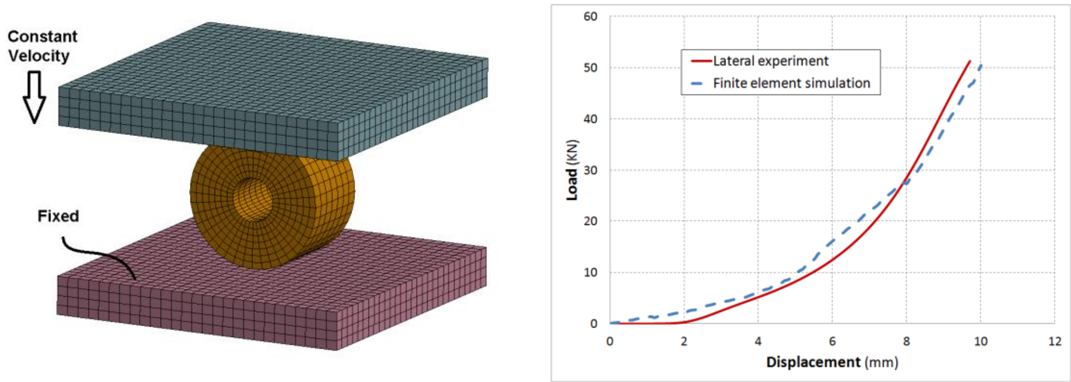

FIGURE 1: COMPARISON OF THE LOAD-DISPLACEMENT CURVES FROM LATERAL JELLYROLL TESTS AND SIMULATION (DIRECT HOMOGENIZATION).

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