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Impact modeling of cylindrical lithium-ion battery cells: a heterogeneous approach

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HIGHLIGHTS

- Compression tests were conducted on flattened jellyroll and its individual layers.
- DMC electrolyte does not significantly change jellyroll's compressive stiffness.
- A heterogeneous FE model was developed to study impact on cylindrical cells.
- Results were compared to those of a homogenized model.
- Results showed a good agreement with experimental data.

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ABSTRACT

In this study, a heterogeneous finite element model was developed in LS-DYNA to investigate lateral impact on 6P cylindrical lithium-ion battery cells manufactured by Johnson Controls Inc. The results were compared to those from a homogenized model previously reported by the authors and also experimental data and showed a good agreement. In order to find the stress-strain curves needed for the finite element simulations, compression tests were conducted on stacks of jellyroll's individual layers, i.e. coated aluminum, coated copper and separator. It was found that the load carrying capacity of the jellyroll comes primarily from the coated aluminum layers. SEM images of the separator layers showed their trilayer structure and how they collapse under excessive compressive loads. Compression experiments were also performed on flattened jellyroll samples after being soaked in electrolyte for 24 h. The measured stress-strain relations showed a very good agreement with the results from a similar set of experiments on dry jellyrolls. This suggested that characterizing dry cells could predict how live cells would react under compression/crash tests without dealing with all the safety provisions needed for those experiments.

1. Introduction

A key aspect in design of lithium ion batteries is to improve the battery's capacity. Having a thinner separator between anode and cathode layers boosts the energy density. However, this can affect the battery's safety by increasing chances of separator failure during battery production or under abnormal conditions. One of the biggest concerns in using lithium ion batteries for automotive applications has been how they react in an accident. Considering that in a hybrid or electric car cells are placed side by side in modules and packs, chances of transverse impact on cells during accidents are higher than other scenarios.

Previous research on structural analysis of lithium ion batteries can be categorized in three groups: laminate level, cell level and pack/module level. In the laminate level, studies have been conducted on characterization of various types of separators, because of their important role in safety and durability of lithium ion batteries. Roth et al. [1] investigated abuse response of lithium ion cells consisting of two commercially available single-layer and three-layer separators and showed that the separator plays a significant role in the overall abuse tolerance of these cells. Sheidaei et al. [2] characterized a single-layer polypropylene separator under tension in machine and transverse directions. They conducted tensile, creep and frequency sweep experiments and showed that the mechanical properties are lower in the case of wet separator. A similar study

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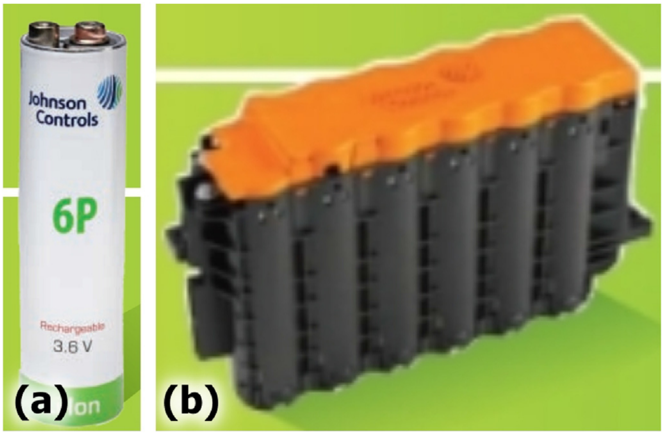

Fig. 1. (a) 6P cylindrical cell and (b) PM12 power module made by Johnson Controls Inc (Source: www.johnsoncontrols.com, 2015).

was reported by Avdeev et al. [3] on a tri-layered polymer separator. They conducted Dynamic Mechanical Analysis (DMA) experiments on both dry and saturated membranes in two perpendicular directions and observed that temperature significantly decreases strength and Dimethyl Carbonate (DMC) electrolyte induces greater compliance. Even though they experience repetitive compressive loads during charge and discharge due to expansion of anode and cathode electrodes, very few studies have been reported on compressive properties of separator membranes. Cannarella et al. [4] used a universal tensile/compression testing machine to find the mechanical properties of a single-layer microporous polypropylene separator over a range of strain rates. They found out that the softening effects due to DMC solvent are less significant in compression than in tension. To study the role of separator compression due to swelling of electrodes on battery performance, Gennady et al. [5] developed a model for predicting the elastic response of a commercial separator at various strain rates. They showed that by combining viscoelastic behavior of the polymer skeleton and poroelastic behavior resulting from the flow of fluid in the pores, the response of the separator can be determined. On the cell level, finding an accurate constitutive model for the jellyroll has always been a concern. Despite the nonlinear behavior of the jellyroll, various homogenization methods have been proposed in the literature to find its average mechanical properties. Greve and Fehrenbach [6] developed a finite element model using pressure dependent isotropic Raghava yield criterion as the constitutive model of the jellyroll and applied Mohr-Coulomb criterion to predict fracture inside the jellyroll. Compression experiments were also performed to find average mechanical properties of the jellyroll as well as individual layers for pouch cells [7,8]. Sahraei et al. [9] used the aforementioned mechanical properties for cylindrical cells of similar chemistry.

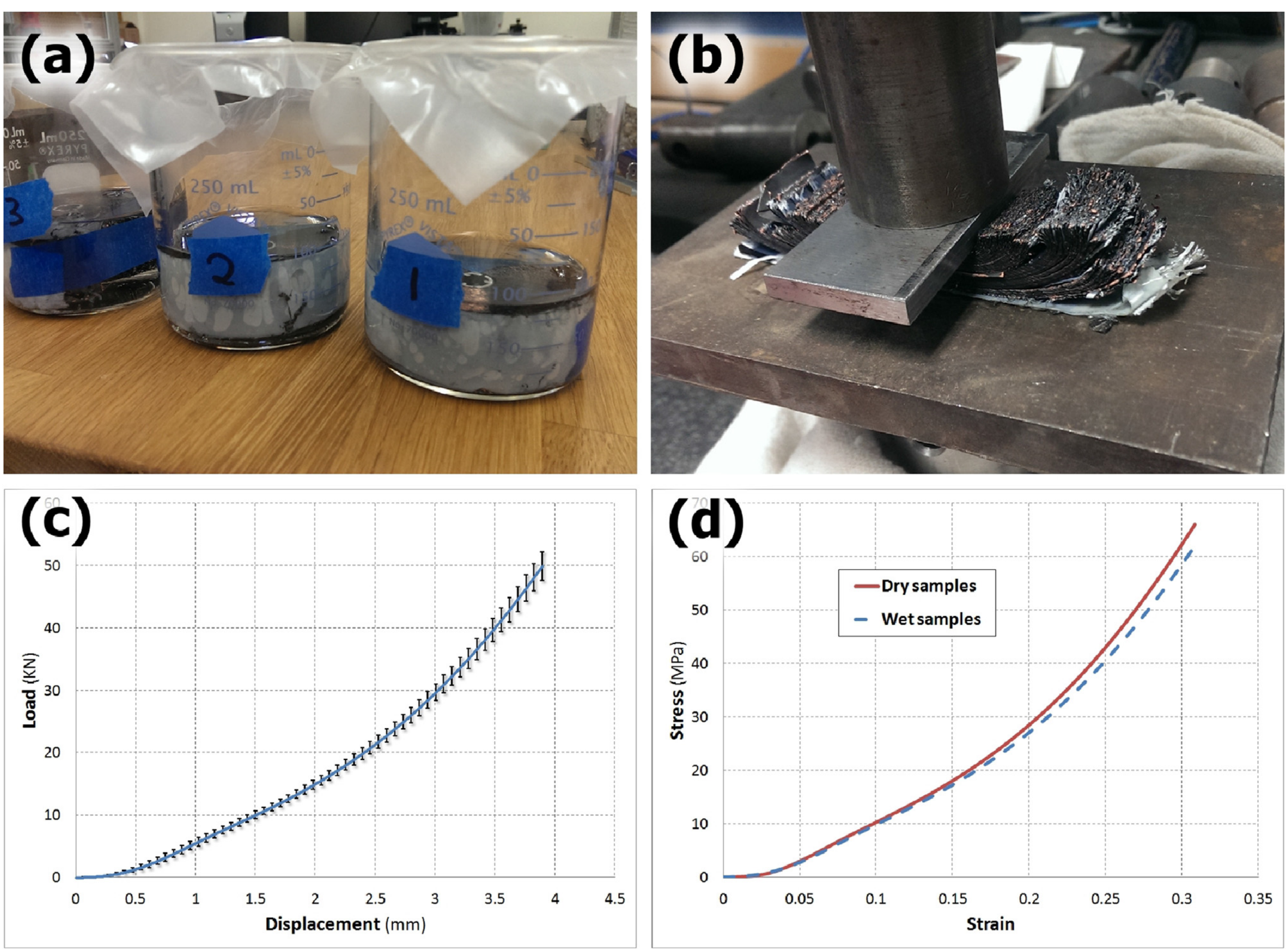

Fig. 2. (a) Jellyroll samples being soaked in electrolyte, (b) Wet jellyroll sample under compression, (c) Load-displacement curve for wet jellyroll samples under compression (n = 3, relative SD = 4.5%) and (d) Stress-strain curve comparison for dry/wet jellyroll samples.