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Clay-like mechanical properties of components for the jellyroll of cylindrical Lithium-ion cells

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Abstract

In this investigation, the stress-strain relations for components of the jellyroll were calculated individually through proposing the micro stressing area. A finite model for jellyroll based on its clay-like mechanical properties was established in HyperWorks/LS-DYNA, which could analyze its mechanical response during deformation and predict the initiation of internal short circuit.Then, the difference of mechanics properties of the jellyroll with changing the thickness of different components was compared through simulation analysis. The simulation results indicate that the mechanics property of jellyroll could be improved through increasing the thickness of the coating active particle.

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Keywords: Lithium-ion battery; Mechanical characteristic; Clay-like; FE model; Micro stressing area

1. Introduction

Lithium ion battery cells are accepted firstly as the power battery used in electric vehicle due to its obvious advantages covering high energy density, high specific power and long deep cycle life. With the rapid popularization of electric vehicle, the safety and reliability of lithium ion battery system have been focus to the automotive industry, especially for some safety accidents caused by electric vehicle recently, which increased the concerning from consumers about the safety of electric vehicle and even prevented its further popularization.

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Currently, the safety of lithium ion battery system is mainly improved through engineering designs and optimization techniques, including improving the structural crashworthiness of car body and battery box to avoid or decrease damage to battery system during crashing accidents. Abuse tests to evaluate the safety of lithium ion battery cells only provide the results of qualified and unqualified, which cannot provide more technical information for the design of battery cells. Better knowing of the mechanisms causing internal short circuits under mechanical loading could provide mechanical parameters for the design of the cells or cell components accordingly and even battery box and decrease the risk of the short circuits and the following thermal runaway or fire behaviours under extreme loading.

Extensive research was carried out to the study of the mechanical properties of individual components of the battery cells under different conditions. Sheidaei et al investigated the tensile behaviour of a single layer polypropylene separator in both dry and wet conditions for both the machine direction and the transverse direction [1]. They found different condition affected its mechanical properties and a very strong anisotropy property in same condition. Wierzbicki et al investigated the mechanical properties of the shell casing and end-caps of the of the 18650 lithium-ion cells[2]. They concluded that the contributions from the shell casing and end-caps to resist deformation could be neglected, compared with the jellyroll. Xiao et al used a finite element based multi-scale approach to analyse the stress of the separator in a battery cell[3]. Zhang et al utilized a set of simulations techniques to systematically study the intercalation-induced stresses developed in particles of various shapes and sizes[4].

Last year, our team had found the clay-like homogenized mechanical property of jellyroll and proposed a linear equation to describe its nonlinear constitutive behavior. However, in reality, jellyroll is an alternating layered structure. In order to reveal the interaction among its components, a more detailed model should be developed, where considers the constitutive behavior of each of component of the jellyroll. In this investigation, the constitutive behaviours of components for jellyroll were found based on the proposed micro stressing area. A finite model for jellyroll was developed, which could be used to predict accurately the deformation behaviour of jellyroll under various loading conditions, the inside stress state of cell during deformation and predict the initiation of internal short circuit. Moreover, a simulation model revealing the change of mechanics characteristics of the jellyroll with different thickness of components was established, including the metal foils and the active particles of lithium metal oxide and graphite, which provides some important information for the design of jellyroll in the terms of safety.

2 Components of constitutive equation for the jellyroll

Due to the different shape and size of the particle bonded on the metal foils, the contact between the active particle and metal foils is nonlinear. In this study, the active particle is considered isotropic and treated as a homogenized material. The influence of the polymeric separator is ignored, due to its small contribution compared with other components, and the deformation of the electrodes is treated in a continuous way.

Force F was applied on the representative micro unit cut from the electrodes, as shown in Fig. 1a. Force state nearby the interface between active particle and metal foils is shown in Fig. 1b. In Fig. 1b, force on cross section of active particle and metal foils is both F due to force balance. Strain ε_1', ε_2' nearby the interface respectively is equal because of the equal vertical displacement nearby the interface between active particle and metal foils. Because the thickness of active particle and metal foils are both in micron magnitude, average strain ε_1, ε_2 for active particle and metal foils are approximately equal to strain ε_1', ε_2' nearby the interface respectively:

$$\varepsilon_1 = \varepsilon_1' = \varepsilon_2 = \varepsilon_2' \tag{1}$$