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The effect of external compressive loads on the cycle lifetime of lithium-ion pouch cells

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ABSTRACT

In application, lithium-ion pouch-format cells undergo expansion during cycling. To prevent contact loss between battery pack components and delamination and deformation during battery operation, compressive pressure is applied to cells in automotive battery modules/packs by way of rigid cell housing within the modules. In this paper, the impact of such compressive pressure on battery degradation is studied. Samples of commercial, 15 Ah $LiNiMnCoO_2$/Graphite electrode pouch-type cells were cycled 1200 times under atmospheric, 5 psi and 15 psi compressive loads. After 1200 cycles, the capacity fade for 0, 5 and 15 psi loads was11.0%, 8.8% and 8.4%, respectively; the corresponding power fade was found to be 7.5%, 39% and 18%, respectively, indicating power fade peaks between 0 and 15psi. This contrasting behaviour is related to the wettability increase and separator creep within the cell after compressive load is applied. The opposing capacity fade and power fade results require consideration from automotive battery engineers at the design stage of modules and packs. In addition to capacity fade and power fade results, the study identified the evolution of compressive pressures over multiple cycles, showing that pressure increases with cycling.

1. Introduction

Lithium-ion (Li-ion) batteries provide an attractive alternative to other battery chemistries in part due to high energy storage density, power delivery density and competitive cost. This has resulted in Li-ion batteries being the preferred solution in electric vehicle (EV) applications. In order to exploit the advantage of Li-ion batteries' high energy and power density, in the design and assembly of battery packs for EVs, cells are compactly packaged. Pouch-format cells undergo expansion during cycling by 6% from rest conditions in the direction normal to the electrode stack [1]. Rigid constraints are applied to the battery pack to maintain packaging compactness, maintain contact between battery components, provide good thermal contact and prevent delamination and deformation during battery operation. A coupling of compact packaging and rigid constraints of Li-ion batteries, at pack level, gives rise to safety issues due to potential overheating of the battery system [2]. The majority of the literature to-date has thus been devoted to understanding the thermal implications of such compact packaging arrangements.

It is well known that under automotive power-draw conditions at ambient operating temperatures, the temperature rise within most Li-ion cells can be significant [3]. Defects in individual cells [4] can further compound the problem by increasing local heat generation [5]. This may lead to thermal runaway of some cells and subsequently the propagation of excessive temperature throughout a module or pack [6]. Much of the literature has therefore focused on 3D thermal modelling of battery packs [2,7–10] and designing thermal management systems [11–14] to address concerns relating to battery pack safety due to significant self-heating.

The mechanical implication of compact, rigid packaging of lithium ion batteries, on the other hand, has seldom been addressed in the literature. Given the lateral expansion of pouch cells during operation [1] and the rigid housings in which pouch cells that make-up battery modules are placed, each pouch cell in a module/pack ensemble will be subjected to dynamic and compressive pressure which varies over the lifetime of the cell [1]. This issue is more pronounced for cell chemistries which employ electrode materials with higher volumetric expansions such as silicon [15].

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Previous studies of in-operando mechanical stress within lithium-ion batteries focus on modelling stress and strain in electrode particles [16,17] due to the formation of intercalation gradients in the solid phase, which is linked to particle fracturing and hence capacity and power fade through the isolation of electrode material, and contact loss, respectively [18,19]. The evolution of compressive pressure due to volume expansion at the macroscopic (i.e., cell level) scale was experimentally quantified by Wang et al. [20,21]. They reported, performance degradation due to volume expansion, primarily due to structural change of cathode materials.

The impact of compressive pressure loads on cell capacity degradation was studied by Cannarella et al. [22] and Peabody et al. [23]. Cannarella et al. applied 7.2, 72 and 720 psi on pouch-type lithium ion cells and reported less capacity degradation for the 7.2 psi condition compared to unconstrained condition, even after 1800 cycles. For higher pressure conditions the capacity drop was much higher than the unconstrained condition. Peabody et al. considered pressure of 145 psi to 4351 psi. Both these studies restricted their investigation to loss of capacity. Thus, none of these studies reported any change of impedance with pressure, which may be significant. With increased pressure i.e. compressive loads on li-ion pouch cells, resistance rise may occur due to elastic creep of the separator [24]. Also, with the exception of the 7.2 psi condition, the external compressive loads studied in Refs. [22,23] are too high to be realised in a practical li-ion battery pack for automotive application.

Although battery ageing has received significant research focus to date, it remains as a key unknown to the original equipment manufacturers (OEM). The mechanisms and physical conditions that lead to accelerated battery degradation are not yet completely understood; the effect of external pressure on battery ageing is one such accelerating factor that is still not understood. The aim of this paper is therefore to measure and quantify any accelerated ageing effects on lithium ion cell performance due to cycling for extended periods under constant pressure, representative of commercial battery packs. The effect of external pressure on impedance rise and capacity drop with cycling is investigated. The experimental setup and procedure adopted in this paper is introduced in Section 2. After presenting the results due to applying pressure and cycling, a discussion of the results is outlined in Section 3. Finally, the key findings are summarised in Section 4.

2. Experimental procedure

Commercially available 15 Ah Li-ion pouch cells with graphite (C_6) negative electrode and $LiNiMnCoO_2$ (NMC) positive electrode were used for this experiment. The cells had a maximum charge voltage of 4.2 V with a minimum discharge voltage of 2.5 V. The manufacturer's recommended maximum 10 s current was 7C for both charge and discharge. The dimension of the cell is 18.6 × 16.5 × 5.6cm. The cells were characterised and cycled with three different externally applied pressures, namely, 0 psi, 5 psi and 15 psi. These pressures were selected in accordance with the estimated pressure within an automotive battery pack. Two cells were tested at each pressure condition and the temperature was kept constant at 25 °C using a temperature chamber.

To emulate the pressure in an assembled automotive pack, 5 psi and 15 psi external pressure were applied to each cell. To achieve a homogenous pressure distribution, cells were sandwiched between two cast iron plates (20 × 20 × 2.5 cm), each weighing 7.35 kg, as shown in Fig. 1. The order of the set up includes a plate, pouch cell, pressure sensor pad and another plate on top (see Fig. 1(a)). The required pressure was achieved by tightening the M8 bolts located at each corner of the iron plates. The Tekscan 5210 N pressure sensor area is made up of 1936 pressure sensing elements,

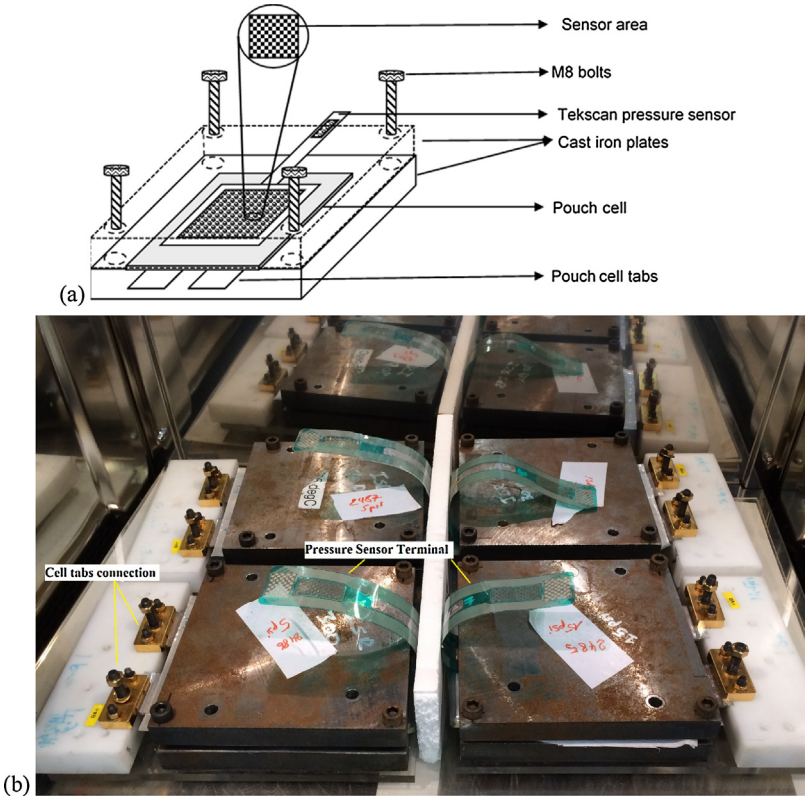

Fig. 1. (a) Schematic of the pressure jig arrangement (b) picture showing the pressure jig set-up of the cells and arrangement, (left) 5 psi cells and (right) 15 psi, respectively.