176 In-situ DIC analysis in crush tests of lithium-ion battery cells

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Abstract. This work shows experiments carried out aiming at determining the internal deformation level suffered by li-ion battery cells subjected to crushing loads. A digital image acquisition system has been set-up in order to acquire pictures of the different layers that constitute the battery cell, with high magnification. Digital Image Correlation analyses have been performed on the pictures, in order to assess the internal deformation and strain levels that are experimented by the materials inside the battery, up to the short circuit occurrence.

Introduction

In recent years, significant research has been carried out for the employment of advanced batteries as an energy storage device, especially Li-ion batteries, in electric-based transportation. Rechargeable Li-ion batteries uses graphite as anode, while a metal oxide is used as the cathode. During cell operation, Lithium ions shuttle back and forth between the two electrodes. While discharging, Lithium ions and electrons are extracted (oxidation) from the anode. The ions cross the ion-conductive electrolyte, through a separator, before ending up in the cathode, whereas the electrons flow in the external circuit. The process is reversed during the charging phase. A limited amount of research is still available in the literature about the mechanical properties and mechanical conditions that lead to a short circuit [1] in Li-ion battery cells. In this work, we wanted to increase the knowledge regarding the internal deformation of lithium polymer batteries when they are crushed until their internal short cut. Several tests have been carried out in different loading configurations, and different techniques have been employed. In particular, in situ imaging and DIC have been adopted to estimate the battery's internal deformation.

Mechanical Abuse Tests

Engineers are asked to design Li-ion batteries and the supporting structures to remain safe when subjected to impacts. Hence, lithium ion batteries must pass a series of safety tests to be certified for use in a particular application. Safety tests are described in international, national and regional standards [2].

Concerning the mechanical deformation, several tests have been developed to evaluate the safety of Li-ion cells. Among them, the crushing test is used to create a small break in the separator, forcing the internal short circuit to occur.

Experimental Test And In-Situ Analysis

The battery used in this work is a small lithium-polymer (LiPo) pouch cell with a nominal voltage of 3.7 V and nominal capacity of 100 mA h (Figure 1a).

a) b) c)

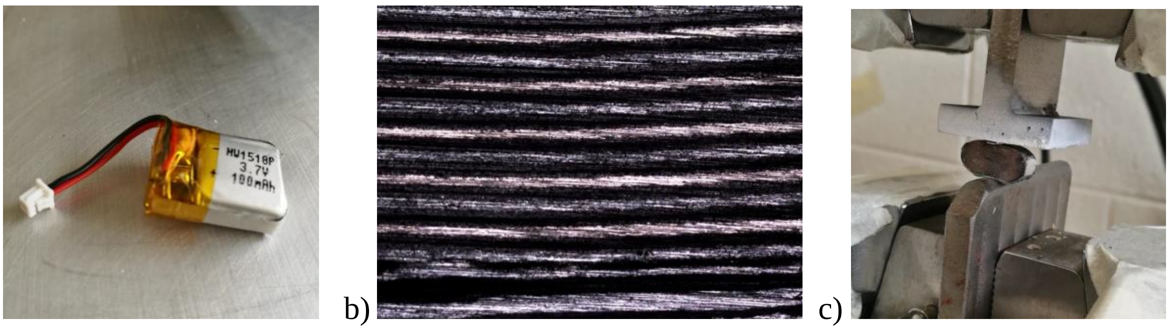
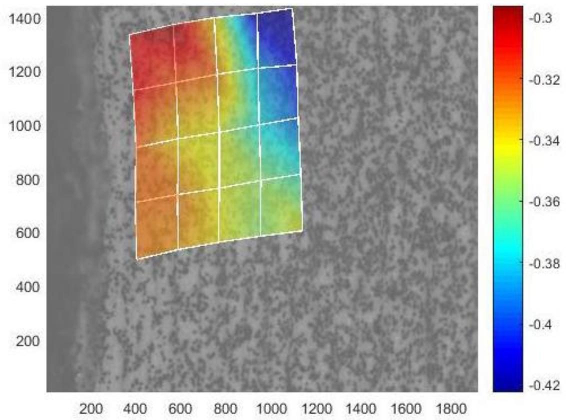


Figure 1: a) Battery used in the test, b) layered structure

The layered structure of the battery is shown in Figure 1b. The entire battery includes 30 anode-cathode pairs, divided into alternate layers of aluminium and copper, sandwiched by the active material; layers are stacked one on top of the other, than wrapped in spiral. The separator layers are put between the anode and cathodes to prevent short circuits, permitting the lithium ions transfer at the same time. The battery cell is crushed by

means of a semi-cylindrical punch, as shown in Figure 1c. The lateral surface of the sample, which has been previously cut and prepared with a micro-scale speckle pattern, is framed by a digital camera, equipped with a 5X-magnification telecentric lens. The resultant field of view is about 1.5x1.2 mm. An in-house developed DIC code has been used to post-process the more than 2,000 pictures saved during a test, where the battery cells was crushed up to 40% of its initial thickness. Difficulties due to large strain and displacements, limited depth of focus, DIC convergence have been faced. The DIC analyses permitted to evaluate the local strain distribution in a limited area in the punch contact area up to 60% of the test duration.
Figure 2a shows a contour map of the axial strain evaluated at the instant highlighted by the red spot in the curve of figure 2b.

a)


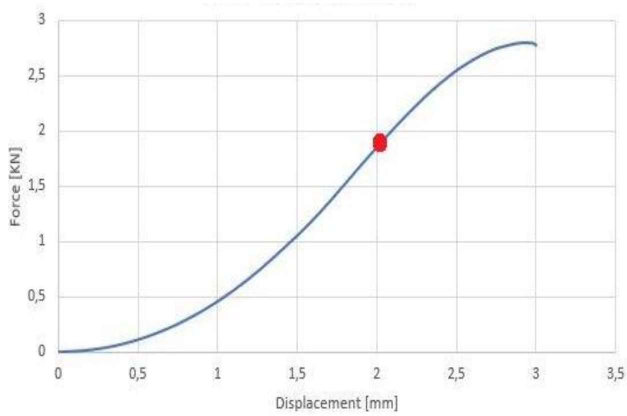
b)


Figure 2: a) strain distribution, b) load-displacement curve

It is noted that the average axial logarithmic strain in the computed zone is about -0.35, with a maximum value of -0.42 which is achieved in the inner part rather than in the punch-battery contact area. The average strain value is consistent with the layer-by-layer distance measured by post-mortem analyses performed at the microscope.
Analogous tests performed on whole, fully operative, battery cells showed that this deformation level nearly correspond to the onset of internal short circuit.

Conclusions

In the paper, the crushing test of a Li-ion battery cells is shown; a semi-cylindrical punch crushed the battery while a digital camera, equipped with a high-magnification telecentric lens, recorded images of the lateral surfaces of the sample. In-situ DIC analysis, permitted to evaluate the internal deformation suffered by the battery, i.e. 0.3-0.4 compressive logarithmic strain, in the layers close to the punch contact area.

References

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