Abstract #539, 224th ECS Meeting, © 2013 The Electrochemical Society

Study of the strain evolution of lithium-ion cells to provide a state of charge and state of health indicators

C. Coutier[1], M. Alias[2], S. Mailley[3], S. Genies[3],
1 CEA, Leti, Minatec Campus - 17, rue des Martyrs, 38054 Grenoble Cedex 9, France
2 CEA, Liten/DTS - 50, avenue du Lac Léman, BP 332, 73377 Le Bourget-du-Lac Cedex, France
3 CEA, Liten/DEHT - 7, rue des Martyrs, 38054 Grenoble Cedex 9, France

This study is dedicated on the measurement of the volume extraction/expansion of lithium-ion cell based on insertion electrode materials during operation. It is well-known that the lattice parameters of electrode materials are modified during lithium ion insertion/desinsertion corresponding charge/discharge process”. For instance, the volume changes between graphite and fully lithiated graphite is around 11%, and is around 4% for $Li_xNi_{1/3}Co_{1/3}Mn_{1/3}O_2$ (NMC) for the insertion rate between x=0 and x=1. The aim of this work is to detect not only the volume change according to the state of charge but also to the state of health. Indeed, the volume variation of cell is linked on one hand to the volume variation of the crystal lattices of the active materials during charge and discharge processes and on the other hand to aging mechanisms leading to the formation of gases which yields an increase of the volume of the cell on a slow and constant way, in contrary to the charge/discharge process for which the volume change is contracted and expanded regularly.

The presentation will give results on 18650 and 26650 commercial cylindrical cells instrumented at a discharge state by strain gauges. Two various designs will be presented. The first one is made of electrodes based on $LiFePO_4$ positive material and on graphite negative material. The second cell-type is made of electrodes based on $LiMn_2O_4$-$LiCoO_2$ blend positive material and on graphite negative material. For this latter design, the winding is coiled on a central mandrel. The type of strain gage used is “rosette” type allowing to measure strain coming from the three directions 0°, 45° and 90° as represented in figure 1.

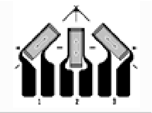

Figure 1: Strain gage rosette with the conventional direction of numeration of the three gauges

Thus, the use of a strain gage rosette allows to determine mathematically the main strain axis from the raw strain values given by the three strain gages oriented towards these three preferentially directions. This calculation allows avoiding positioning identically the gauges on the surface of the cells, because the main strain axis will be determining by correlating the raw values. Therefore, we do not specify a preferential positioning of the rosette gauge on the cell and the raw signals can vary from a strain gaue from another one. The formula to calculate the main strains are well known. The parameters *d* (Equation 1) and *r* (Equation 2) are calculated from the raw strains ε_1, ε_2 and ε_3 measured by the gauges Nb1, Nb2 and Nb3 respectively. The calculation convention imposes to numerate the strain gages from 1 to 3 as shown Figure 1. The gauge Nb2 has to be at 45° from the gauge Nb1 and the strain gage Nb3 has to be at 90° from the same strain gage Nb1, according to the rotation direction. From *d* and *r*, the main strains *Ep* and *Eq* can be obtained and are given by Equation 3 and Equation 4 respectively.

$$d = \frac{\varepsilon_1 + \varepsilon_3}{2} \qquad \textit{Equation 1}$$

$$r = \frac{1}{\sqrt{2}}\sqrt{\left(\varepsilon_1 - \varepsilon_2\right)^2 + \left(\varepsilon_2 - \varepsilon_3\right)^2} \qquad \textit{Equation 2}$$

$$Ep = d + r \qquad \textit{Equation 3}$$

$$Eq = d - r \qquad \textit{Equation 4}$$

The results obtained during discharge are given in the figure 2 for the first type of cell and in the figure 3 for the second type of cell.

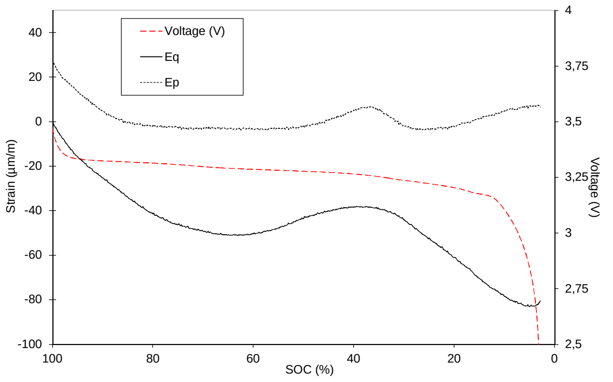

Figure 2: Voltage and Ep and Eq strain profiles during discharge for C/$LiFePO_4$ cell (at C/10 current rate)

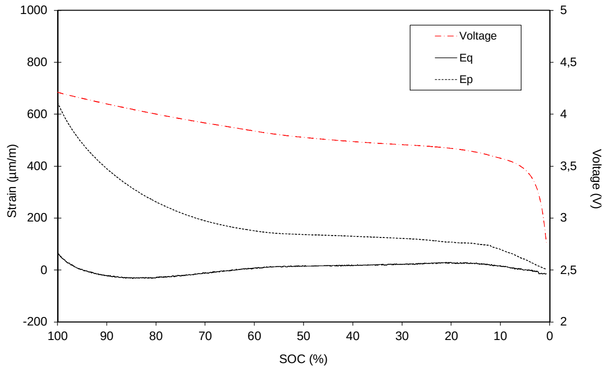

Figure 3: Voltage and Ep and Eq strain profiles during discharge for C/ $LiMn_2O_4$-$LiCoO_2$ cell (at C/10 current rate)

If we observe more particularly *Eq* which evolves between 0µm/m and -80µm/m, we note a continuous evolution up to 30% of SOC, then a decrease of the strain and finally a new increase after 60% of SOC. We have noticed that the strains for the second cell present very important variations of Ep, from 0µm/m to 650µm/m, more important than for the first cell, and moreover the *Ep* and *Eq* profiles are not similar like the first cell. The difference of evolution can be linked to the nature of the materials. Besides the strain amplitude is more specifically connected to the internal design. When a central mandrel is present, the volume expansion of the electrodes pushes more particularly towards the external direction of the case. Without a mandrel, the volume expansion is absorbed simultaneously inside and outside the winding of the cell, and hence the strain of the gage attached to the outer face of the metal cylinder is smaller.

We will show that the principal influent parameters are (i) the presence of a mandrel in the middle of the rolling, (ii) the nature of the metal case (stainless steel, aluminum), (iii) the thickness of the case wall, (iv) the number of electrode winding/amount of the active material per unit area, (v) the nature of active materials and (vi) the state of aging. The strain signature depends on these parameters.