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Systematic Approach of High-Power NCA 18650 Cylindrical Cells considering Vibration and Shock Tests for Electric-Powered Application

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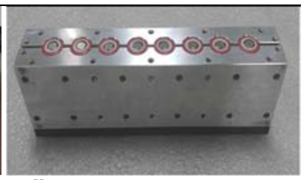
Abstract

Currently, the high-power Li[NiCoAl]O_2 (NCA) 18650 cylindrical cell has been increasingly interested in industry and considered as an operating source in electric-powered application such as electric-vehicle (EV) and frequency regulation battery energy storage system (FRBESS) that basically require high C-rate in a short period of time. For this reason, this research properly provides good information of high-power NCA 18650 cells from systematic approach based on environmental tests, state-of-charge (SOC) and degradation for state-of-health (SOH). From environmental tests of vibration and shock with some conditions, discharge capacities and internal resistances are compared before and after. Electrical circuit modelling (ECM)-based SOC estimation considering extended Kalman filter (EKF) and cell degradation considering cycle-life test are additionally carried out and analysed. Consequently, according to this systematic approach, it is capable of providing the solution for stable and efficient operation of electric-powered application.

1 Introduction

Nowadays, because of increased necessity of electric-powered application such as electric vehicle (EV) and frequency regulation battery energy storage system (FRBESS) requiring high pulse rate in a short period of time, the significance on the high-power Li[NiCoAl]O_2 (NCA) 18650 cylindrical cell has been emphasized in industry. After high-power NCA cell selection, the next task to do is to check the cell's electrochemical characteristic with a specific operating condition. The use of high-capacity (high-energy density) NMC cell may result in inefficient operation (NMC; Li[NiMnCo]O_2). In spite of their same shape (18:width, 65:length, 0:circle), difference in electrochemical characteristics caused by the internal material should be definitely checked. Therefore, it is absolutely required to precede various experiments and detailed analysis to judge the feasibility of high-power NCA cell in electric-powered transportation. This precedence is very helpful for designing well-established battery management system (BMS). For this objective, this research aims to introduce the systematic approach of high-power NCA 18650 cylindrical cells based on environmental tests of vibration and shock tests. With and without these tests, two main factors such as discharge capacity (CC-CV) and hybrid pulse power characterization (HPPC)-based internal resistance are compared. This research develops this systematic approach one step further by showing state-of-charge (SOC) estimation using the electrical circuit modelling (ECM) and cycle-life test based aging for state-of-health (SOH). This research has been elaborately verified by above experimental results of the NCA cell with a rated capacity of 2.0Ah by LG Chem, Ltd (maximum discharge current 8C, it is called as 18650HE2) [1]. In this perspective, this research provided the good solution for stable and efficient operation of electric-powered transportation.

2 Proposed research



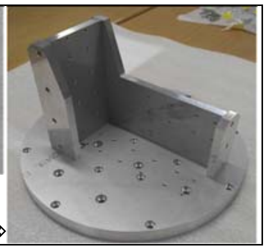


Fig. 2: Cell zig that includes 8 NCA cells.
⇦ Fig. 1: Eight cells simultaneous holder for discharging/charging.
Fig. 3: Main zig that includes three cell zigs (X,Y,Z axis). ⇨

As previously mentioned Section 1, environmental tests of vibration and shock were applied to high-power NCA 18650 cylindrical cells (18650HE2). To check the influence on electrochemical characteristics caused by vibration and shock tests, two parameters of discharge capacity and internal resistance are measured and compared before and after using cell holder of Fig. 1. Fig. 2 shows the cell zig that can includes eight NCA cells simultaneously. This research considered three cell zigs each corresponding X,Y,Z axis in main zig of Fig. 3. The main zig is installed in each experimental setup for vibration and shock (see Figs. 4 and 7). For reference, it is assumed that there is little structural difference in cell and main zigs. The main zig contains 24 NCA cells that comprised 8 cells in X-axis,8 cells in Y-axis, and 8 cells in Z-axis, respectively.

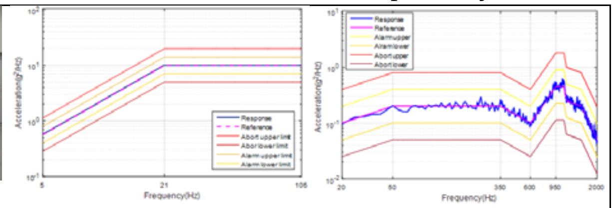
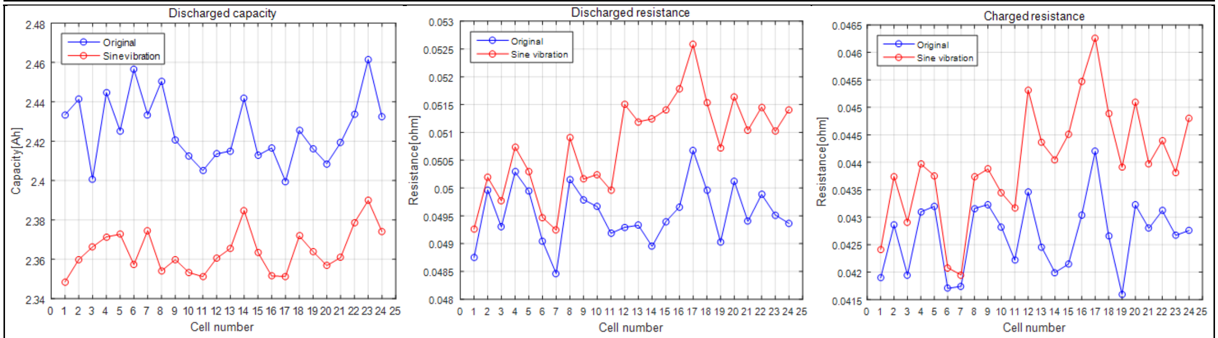


Fig. 4: Experimental apparatus for vibration test.
Fig. 5: Measured acceleration of sine vibration [10grms] and random vibration [20grms]. ↗



Rate of change of discharge capacity : -2.5348% Rate of change of discharge resistance : 2.4942% Rate of change of charge resistance : 3.1116%

Fig. 6: Comparison of two parameters with and without vibration test: (left) discharge capacity with sine vibration, (middle) discharge resistance with random vibration, (right) charge resistance with random vibration.

In case of vibration test, measured acceleration of sine vibration (10grms) and random vibration (20grms) within a total range of frequency 20-2000Hz were applied. At a specific axis condition (X,Y,Z), four times in sine vibration were considered during 16 minutes (once: four minutes). In rotation on three axis (Y,Z,X ⇨Z,X,Y), a total of 48 minutes was applied in 24 NCA cells. The consideration of vibration tests results in decreased discharge capacity and increased discharge/charge resistances (see Fig. 6). Specifically, the range of change of charge resistance is larger than that of discharge resistance. This research considered the shock test considering acceleration of half-sine shock based on two rules of 100g and 260g during 4.8ms (Fig. 8). According to similar axis condition with that of vibration test, 12 times in half-sine shock were applied at a specific axis condition (X,Y,Z), thus a total of 36 times was applied in 24 NCA cells under rotation on three axis (Y,Z,X ⇨Z,X,Y). From experimental results of Fig. 9, the influence on discharge capacity and internal resistances caused by shock test is almost identical with that of vibration test. In this overall perspective, it is possible to have useful information on different electrochemical characteristics of high-power NCA cell to prepare for real situation of electric-powered application (unexpected external vibration and shock). It is shown that there is little influence on vibration and shock in main and cell zigs from the tendency of change of internal parameters.

Three approaches were carried out in this research. First of all, two ECM (Fig. 10)-based SOC estimations of high-power NCA cell considering vibration and shock tests are displayed in Fig. 11. Regardless of any environmental test, our SOC estimator guarantees the reliable SOC performance.

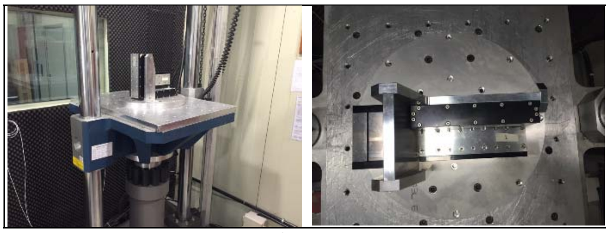


Fig. 7: Experimental apparatus for shock test.

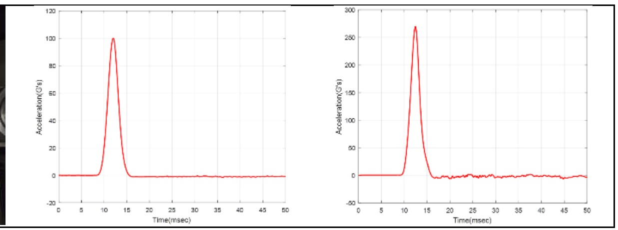
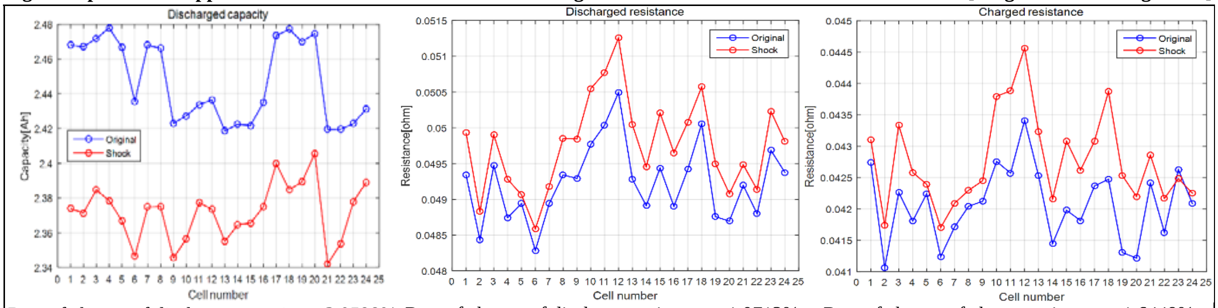


Fig. 8: Measured acceleration of half-sine shock [100g 4.8ms and 260g 4.8ms]



Rate of change of discharge capacity : -3.0598% Rate of change of discharge resistance : 1.0713% Rate of change of charge resistance : 1.6449%

Fig. 9: Comparison of two parameters with and without half-sine shock test during 4.8ms: (left) discharge capacity with 100g, (middle) discharge resistance with 260g, (right) charge resistance with 260g.

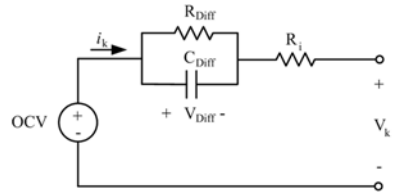


Fig. 10: Equivalent electrical-circuit modelling.

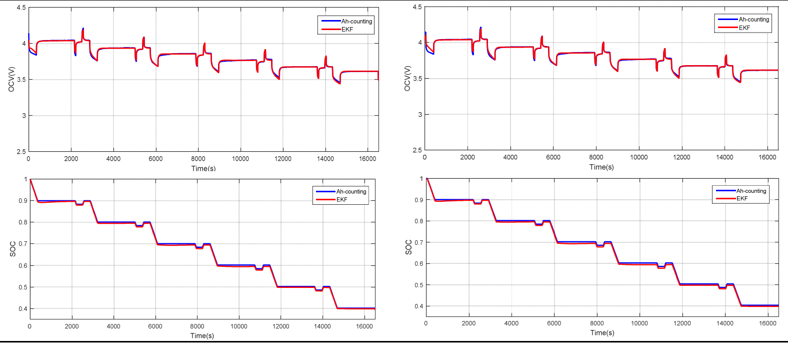


Fig. 11: ECM-based SOC estimation of high-power NCA cell using the EKF : (left) vibration, (right) shock ⇨

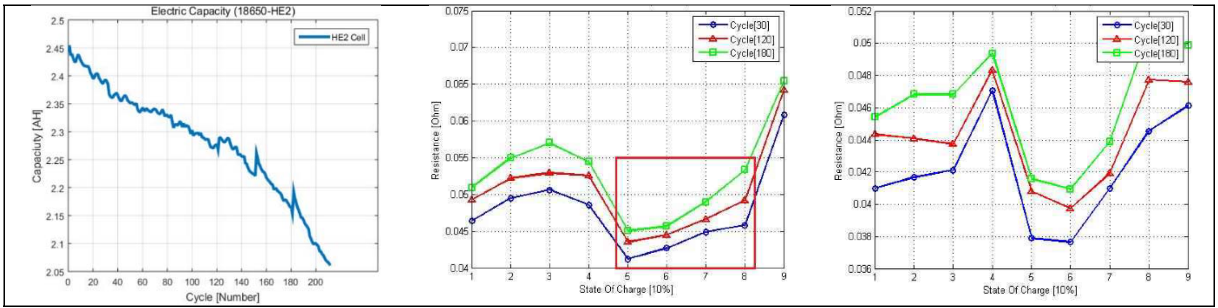


Fig. 12: Additional experimental results for state-of-health (SOH): (left) Change of discharge capacity with cycle-life test (200 days), (middle) change of discharge resistance with cycle-life test (200 days) and within SOC 10-90%, (right) change of charge resistance with cycle-life test (200 days) and within SOC 10-90%.

The influence on degradation from cycle-life test can be checked in Fig. 12. The purpose of Fig. 12 is to get information of the SOH. During 200 days, the cycle-life test with repetition of CC-CV scheme was applied to high-power NCA cell. Increased discharge/charge resistance with regard to long period of time of cycle-life test can be shown. For reference, this research has a plan to introduce various analytic results using scanning electron microscope (SEM), electrochemical impedance spectroscopy (EIS), and X-ray diffusion (XRD). Among them, this full abstract firstly shows the SEM image of positive electrode of 18650HE2 (Fig. 13).

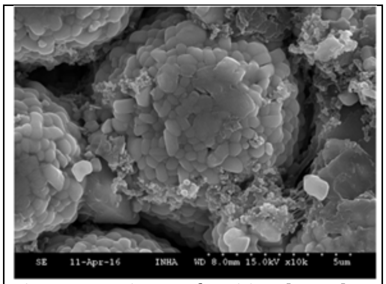


Fig. 13: SEM image of positive electrode.

Acknowledgments

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References

[1] https://www.powerstream.com/p/LG-ICR18650HE2-REV0.pdf