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Simultaneous Comparison of Internal Electrical Characteristics of Various 18650 Rechargeable Cells Under Excessive Half-Sine Shock for Railway Application

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Summary

Electric-powered transportations such as electric vehicles (EVs) and energy storage system (ESS) absolutely require robust series/parallel-cell configured battery packs to satisfy high-power/energy specification. Then, the most important task to be considered is to guarantee high reliablity under unexpected hazardous condition. For this purpose, it is priorly required to evaluate various cells under environmental/safety tests and to select an optimal cell subsequently. Thus, some rechargeable 18650 lithium-ion cylindrical cells are simultaneously evaluated by comparison of internal electrical characteristics under excessive half-sine shock of 1000g as a assumption of unexpected hazardous condition. This research considered eight 18650 lithium-ion cylindrical cells according to three internal materials (NCA; $Li[NiCoAl]O_2$, NMC; $Li[NiMnCo]O_2$, and LFP; $LiFePO_4$) filled inside cell and cell' external widths (18.2-18.4mm). After half-sine shock test in X,Y,Z axes based on the procedure predetermined, discharge capacities and discharge/charge resistances of eight cylindrical cells are compared before and after. Because of an internal damage caused by excessive half-sine shock test, it is clearly known that all discharge capacities and discharge/charge resistances are respectively more decreased and increased than before. Specifically, from these experiments and its comparison, it is possible to determine an optimal 18650 lithium-ion cylindrical cell with less damage against excessive half-sine shock. A solution for providing information on cell's material, series/parallel numbers in the battery pack for satisfying various requirements of electric-powered transportations is also suggested. In terms of power electronics-based issue, this research can be anticipated to lead the way to achieve a well-designed battery management system (BMS) for efficient discharging/charging operation of electric-powered transportations

Keywords: 18650 rechargeable cells, Half-sine shock, Resistances, Battery management system

Proposed Approach

Table 1: Detailed specification of five NCA cells, two NMC cells and one LFP cell (total 8 cells)

	NCA (Li[NiCoAl]O_2)					NMC (Li[NiMnCo]O_2)		LFP($LiFePO_4$)
	18650-HE2 (LG Chem.)	18650-HE4 (LG Chem.)	18650-20R (Samsung SDI)	18650-A (Molicel)	18650-C (Molicel)	18650-29E (Samsung SDI)	18650-J (Molicel)	18650-M1A (A123)
Rated capacity	2.5Ah	2.5Ah	2.0Ah	2.5Ah	2.0Ah	3.5Ah	2.37Ah	1.1Ah
Nominal vol.	3.6V	3.6V	3.6V	3.6V	3.6V	3.635V	3.7V	3.3V
Max. cont. current (dis)	20A(8C)	20A(8C)	22A(11C)	20A(8C)	20A(10C)	10A(2.86C)	5A(2.11C)	30A(27C)
Recommend current (ch)	1.25A(0.5C)	1.25A(0.5C)	4A(2C)	2.5A(1C)	2A(1C)	1.75A(0.5C)	1.25A(0.53C)	1.5A(1.36C)
Cutoff vol.	2.5-4.2V	2.5-4.2V	2.5-4.2V	2.0-4.2V	2.0-4.2V	2.5-4.2V	3.0-4.2V	2.0-3.6V
External width	18.3mm	18.3mm	18.3mm	18.4mm	18.4mm	18.3mm	18.2mm	18.2mm

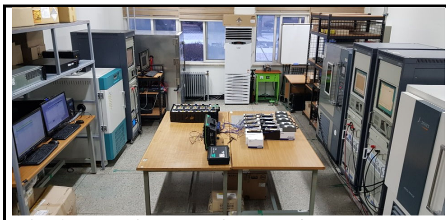

Fig. 1: Experimental discharge/charge testers (Discharge capacity, internal resistances).

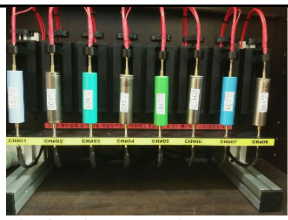

Fig. 2: Eight cells simultaneous holder for discharging/charging.

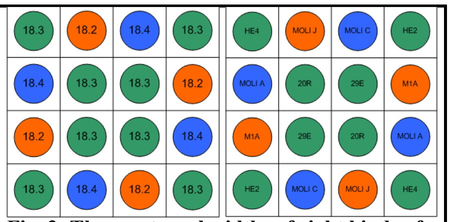

Fig. 3: Three external widths of eight kinds of cells included in one zig (18.2-18.4mm).

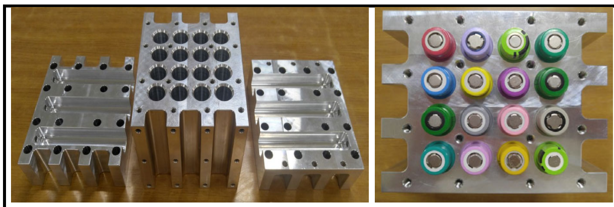

Fig. 4: Cell zig simultaneously including 32 lithium-ion cells (eight kind of cells × 2 × 2(front/back) =32 lithium-ion cells).

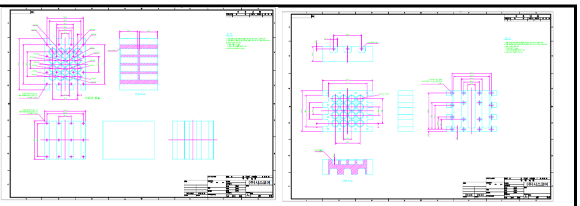

Fig. 5: Partial cross-sectional diagrams of the cell zig.

As Aforementioned in extended summary, eight 18650 lithium-ion cylindrical cells that have three materials including Li[NiCoAl]O_2 (NCA), Li[NiMnCo]O_2 (NMC), and $LiFePO_4$ (LFP). Each detailed specification of eight lithium-ion cells are listed in Table 1. Additionally, it is known that these cells have each external width within 18.2-18.4mm. Based on these variabilities among lithium-ion cells, excessive half-sine shock tests are done. Above all, as shown in Figs. 1 and 2, to compare the cell's influence on internal electrical characteristics before and after excessive half-sine shock, two representative parameters such as the Ampere-counting based discharge capacity and hybrid pulse power characterization (HPPC)-baesd discharge/charge resistances of all above lithium-ion cells are previously measured. The cell zig displayed in Figs. 3 through 5 simultaneously includes 32 lithium-ion cells (eight kind of cells×2×2_front/back). This cell zig was designed to minimize cell-to-cell variance due to excessive half-sine shock. Partical cross-section diagrams of the cell zig is shown.

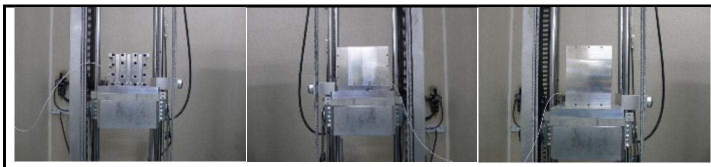

Fig. 6: Excessive half-sine shock test in X(left),Y(middle),Z(right) axes

Table 2: Procedure of excessive half-sine shock test (32 cells in a group)⇨

Peak acceleration	Pulse duration
Over 1000g	0.5ms
Group1	Nine times (All axes(X⇨Y⇨Z)) (Three times per one axis) – 32 cells(f/b)
Group2	Three times (X axis) – 32 cells(f/b)
Group3	Three times (Y axis) – 32 cells(f/b)
Group4	Three times (Z axis) – 32 cells(f/b)

An experimental apparatus for conducting excessive half-sine shock at three axes (X,Y,Z) are shown in Fig. 6 at a same time. Peak acceleration over 1000g was applied during 0.5ms pulse. Table 2 lists the procedure of excessive half-sine shock test. At the front of the zig, a total of 16 cells consisting of eight kind of cells×2 are concurrently included (Fig. 3). Likewise, the remainder of cells is included at the back of the zig (16cells). Therefore, four identical cells at the front (2) and back (2) of the zig amomg 32 cells are considered in above test. Four groups are set according to the procedure listed in Table 2. In case of Group1, a total of nine times was applied in experimental cells in rotation on three axes (X,Y,Z⇨X,Y,Z⇨X,Y,Z). Group2 through 4 only considered one axis (Group2-X,Group3-Y,Group4-Z) at three times. Thus, there is no rotation on three axes. After excesive half-sine shock test of Group1 through 4, it is required to measure two internal parameters of the discharge capacity and discharge/charge resistances to evaluate cell's performance. Before and after test, the results for simultaneous comparison of internal electrical characteristics are shown in Figs. 7 through 9.

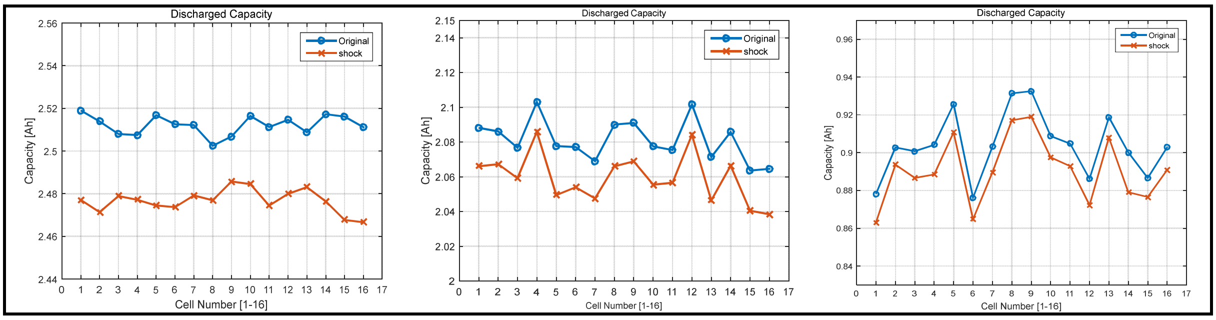

Fig. 7: Changes of discharge capacities of three arbitrary selected 18650 lithium-ion cylindrical cells [No.1-4; Group1 (X⇨Y⇨Z axes rotation_9times), No.5-8; Group2 (only X axis_3times), No.9-12; Group3 (only Y axis 3times), No.13-16;Group4 (only Z axis _3times)] caused by excessive half-sine shock of 1000g; (left) 18650-HE4 (NCA), (middle) 18650-C (NCA), (right) 18650-M1A (LFP) (Rate of changes of discharge capacity : -1.41175%, -1.04063%, and -1.47057% respectively).

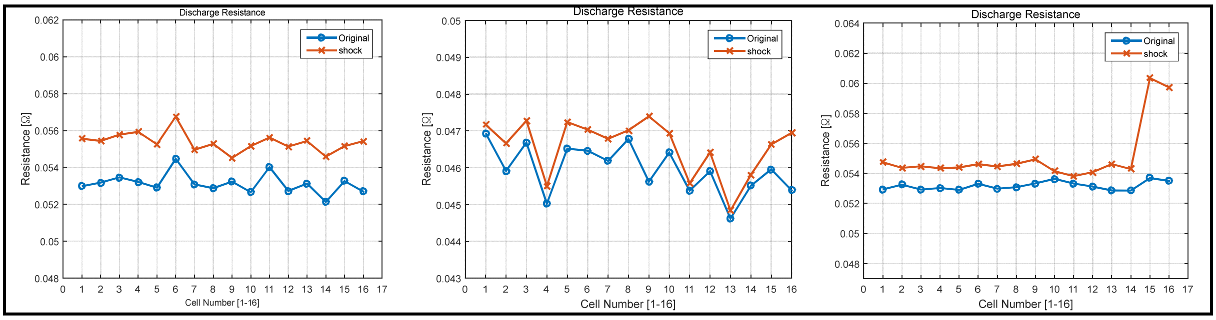

Fig. 8: Changes of discharge resistances of three arbitrary selected 18650 lithium-ion cylindrical cells [No.1-4; Group1 (X⇨Y⇨Z axes rotation_9times), No.5-8; Group2 (only X axis_3times), No.9-12; Group3 (only Y axis 3times), No.13-16;Group4 (only Z axis 3times)] caused by excessive half-sine shock of 1000g; (left) 18650-HE4 (NCA), (middle) 18650-A (NCA), (right) 18650-20R (NCA) (Rate of changes of discharge resistance : 4.23249%(remarkable), 1.35357%, and 3.66421% respectively).

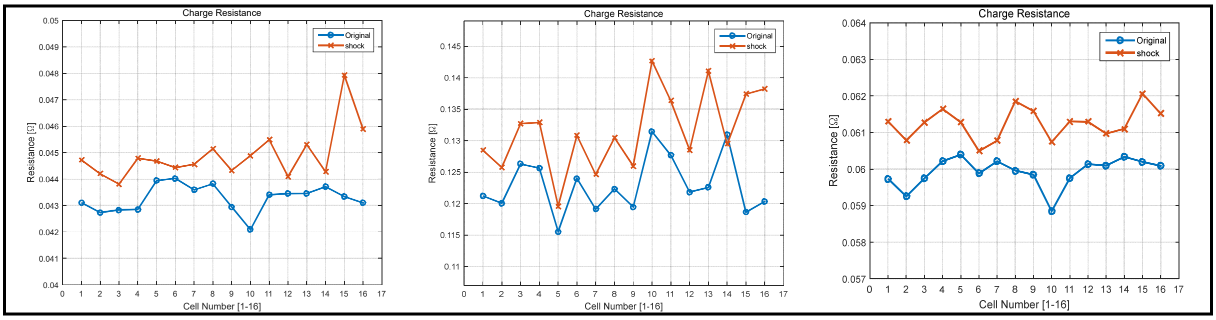

Fig. 9: Changes of charge resistances of three arbitrary selected 18650 lithium-ion cylindrical cells [No.1-4; Group1 (X⇨Y⇨Z axes rotation_9times), No.5-8; Group2 (only X axis_3times), No.9-12; Group3 (only Y axis 3times), No.13-16;Group4 (only Z axis _3times)] caused by excessive half-sine shock of 1000g; (left) 18650-HE2 (NCA), (middle) 18650-J (NMC), (right) 18650-29E (NMC) (Rate of changes of charge resistance : 3.78289%, 7.04383%(remarkable), and 2.22314% respectively).

It is shown that all sub-figures in Figs. 7 through 9 considered X-axis as ‘Cell number [1-16]’. The meaning of ‘1-4’ is four identical cells experimented in Group1. In the same manner, ‘5-8’, ‘9-12’, and ’13-16’ denote used four identical cells in Group2, Group3, and Group4 respectively. Fig. 7 shows the changes of discharge capacities of three arbitrary selected cells among eight different 18650 lithium-ion cells (18650-HE4(NCA), 18650-C(NCA), and 18650-MIA(LFP)). After excessive half-sine shock test, all discharge capacities of three cells are decreased regardless of cell’s internal material. There is little difference in discharge capacity among three cells. It is checked that the decreased discharge capacity is little dependent on the number of half-sine shock and axis direction. After test, the changes of discharge/charge resistances of each three cells are shown in Figs. 8 and 9 respectively. Three cells of 18650-HE4(NCA), 18650-A(NCA), and 18650-20R(NCA) were selected to compare cell’s discharge resistance. The performance on cell charging is evaluated by comparison of cell’s charge resistance of 18650-HE2(NCA), 18650-J(NCA), and 18650-29E(NMC) priorly selected. All discharge/charge resistances are increased irrespective of cell’s internal material. Additional analyses of the resistances are similar with that of the discharge capacity. Finally, from these experiments and its comparison, it can be expected to provide the solution for selection of an optimal 18650 lithium-ion cell with less demage against any risk/failure. Useful information on cell’s material and the number of series/parallel in the battery pack will be sufficiently provided for efficient discharging/charging of electric-powered transportations.

Acknowledgments

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