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Electrical and structural studies of lithium-ion battery

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Abstract

Lithium ion batteries are lifeline for consumer electronic devices and large scale batteries are grown rapidy for e-mobility, renewable energy, stationary and energy storage solutions due to its superior electrochemical characterstics,multiple chemistries and design as well. Hence, this paper discuss the electrical properties of 18650 cylindrical type of lithium-ion battery for different C-rates at ambient temperature. The electrical test results showed that the capacities are found to be 96% and 98.6% for the C-rates at 1.0C and 0.1C respectively. The performance of the Lithium-ion battery is closely related to the chemistry of the cathode. The structural studies on the cathode materials were carried out by X-ray diffraction. The structural analysis confirmed the cathode chemistry is lithium cobalt oxide and the electrical results correlated and discusssed to understand safety level of the lithium-ion battery.

Keywords: Lithium-ion cells, Lithium cobalt oxide, X-ray diffraction, Electronic devices, Electric vehicles.

1. Introduction

The battery is an electrochemical energy storage device which converts the chemical energy into electrical energy. These energy storage devices are commonly referred as either secondary or rechargeable batteries [1-5]. The electrical performance and safety of any battery depends on the chemistry of materials and their electrode kinetics during charging and discharging processes. The most promising and globally recognized battery technologies based on the different chemistries are: Lead acid battery, Nickel cadmium, Nickel metal hydride, Lithium ion, Sodium-Sulfur batteries, etc., which are considered as traditional storage batteries. In view of changing application requirement and also operating environment; several rechargeable batteries are being developed for the e-mobility, industrial, renewable and stationary applications. The potential battery technologies are: Lithium-ion, Redox flow batteries, Sodium-ion batteries, Lithium-Sulfur, Nickel–zinc, Dual carbon, Magnesium, Aluminum, Metal-air batteries, etc. [1-5].

Among all, the lithium-ion battery technology is considered to be apt and versatile chemistry for present consumer electronic devices including health care tool kits and also emerging applications such as electric vehicle, renewable energy, stationary and energy storage solutions.

The lithium-ion cells are available in various types and prominent designs such as: button, cylindrical, pouch and prismatic type [2-4].The button type and pouch type of cells are used for portable electronic gadgets including health care kits such as smart bands, etc. The cylindrical and prismatic type of cells are used in laptops, electric vehicles and stationary applications respectively. The commercial lithium-ion batteries and possible applications are shown in the Figure 1.

Figure : Lithium-ion batteries and Applications

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The lithium ion battery technology is lifeline for all portable consumer electronic devices due to its superior electrochemical characteristics in terms of foot print, operating voltage, energy density, charge acceptance, cycle life, rate capability, etc., as compared to commercial available rechargeable batteries [1-4]. The electrochemical working principle of the lithium-ion cell during cycling process is shown in the Figure 2.

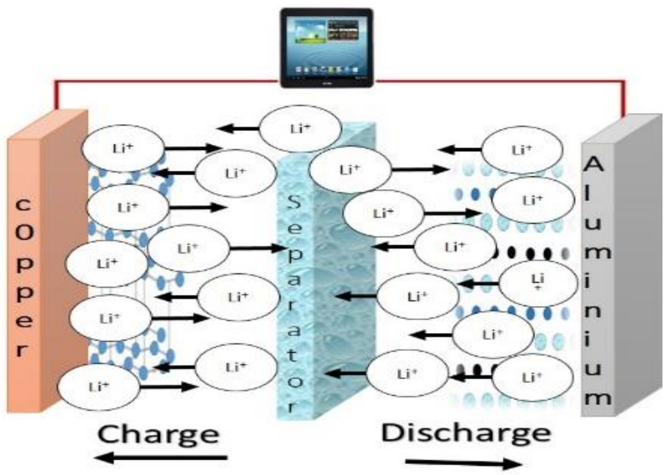

Figure 2: Electrochemical reaction of the Lithium-ion cell during charge and discharge process.

From the Fig. 2, it is shown that the copper (Cu) and aluminium (Al) foils are used as current collectors respectively for anode and cathode electrodes. For example, the Lithium Cobalt Oxide cathode material was coated on the Al foil. Similarly, the graphite anode material was coated on the Cu foil. The electrolyte is the mixture of organic solvents and lithium salt. The common electrolyte consists of Ethylene Carbonate (EC), Di-Ethyl Carbonate (DEC), and Lithium hexafluoro phosphate ($LiPF_6$) salt. The lithium ion cell based on Lithium Cobalt Oxide (LCO) as cathode and Carbon as anode in the organic electrolyte is expected to deliver the capacity in the range of 135 to 150mAh/g at standard load and potentials. The possible electrochemical reactions at the cathode and anode compartments and the total electrochemical reaction in the lithium-ion cell is shown below [2-9].

$$\mathbf{LiCoO_2 \underset{d}{\overset{c}{\rightleftharpoons}} Li_{1-x}CoO_2 + xLi^+ + x\,e^-}$$

$$\mathbf{C_n + xLi^+ + x\,e^- \underset{d}{\overset{c}{\rightleftharpoons}} C_nLi_x}$$

$$\mathbf{LiCoO_2 + C_n \underset{d}{\overset{c}{\rightleftharpoons}} Li_{1-x}CoO_2 + C_nLi_x}$$

The electrochemical reaction during discharge process; the lithium-ions are extracted from the carbon anode and then inserted into the cathode electrode host and simultaneously corresponding number of electrons will flow through the external circuit.

In the case of charging process, lithium-ions are extracted from the cathode and then inserted in the carbon anode. It means that the lithium-ions are intercalated and de-intercalated in and from cathode during the discharge and charge processes respectively. In other words, the lithium ions moves between the anode and cathode during cycling.

The LCO cathode material is extensively used in the lithium-ion cells in particularly for consumer electronic devices. However, the cobalt is relatively expensive and also hazardous. Hence, several cost effective and environmental friendly materials with layer, spinel and olivine structure materials were developed [2-9] The most promising cathode materials are Lithium Nickel Oxide (LNO), Lithium Manganese Oxide (LMO) and Lithium Iron Phosphate (LFP), etc., are used as cathode candidates for the lithium-ion batteries. Further, the multivalent dopant of metals in the composite cathode materials were developed to reduce the cobalt content and improve the performance of the battery. The Lithium Nickel Manganese Cobalt Oxide (LNMC) and Lithium Nickel Cobalt Aluminum Oxide (LNCA) cathodes were improved energy density, cycle life and safety as compared to the LCO cathode based lithium-ion battery.

The lithium-ion battery consists of organic electrolytes which is sensitive to the charging potentials. The overcharging of the battery may leads to undesired chemical reactions within the active materials and electrolyte species which in turn generates heat in the cell. The design of lithium ion battery integrated with battery management system (BMS) and thermal management system (TMS) are critical for the safety of the large energy storage battery for the automotive or industrial applications [9-10].

One of the most proven design of the lithium-ion battery is cylindrical (18650) type with the dimensions of 18 mm diameter and 65 mm height. The necessary protective circuit is integrated within the cell to control the voltage during cycling. The cylindrical type of 18650 cell developed exclusively for the laptop computers and power bank devices. The similar geometry of these batteries are being developed for large scale energy storage applications such as electric vehicles and stationary requirements. Therefore, we have made an attempt to understand the electrical characteristics of the 18650 cylindrical type of lithium-ion cell at different C-rates and also identified the chemistry as well. The experimental electrical and structural results are correlated and discussed to understand the performance and safety of the battery technology.

2. Experimental

The commercial 18650 cylindrical type lithium-ion cells were considered for electrical studies and also to understand the structure the cathode. The specifications of the 18650 cylindrical type of single lithium-ion cell is presented in the Table 1.

Table 1: Specifications of the 18650 Li-ion cells

Lithium-ion cell		Specifications
	Chemistry	Li-Cobalt Oxide
	Type	Cylindrical
	Model	18650
	Dia or width	18 mm
	Height	65 mm
	Nominal voltage	3.7V
	Capacity	2.6Ah

In order to understand the lithium-ion battery pack performance; two numbers of 18650 lithium-ion cells were connected in series to increase the voltage to 7.4V. The electrical tests were carried out on battery pack (specification of 7.4V and 2.6Ah) using battery life cycle tester. The battery pack performance was evaluated in the potential range of 8.4V-5.5V for charge and discharge cut-offs respectively. The performance of lithium-ion battery is closely depend on the electrode structure and hence the structural studies on the cathode material was carried out by the X-ray diffraction.

3. Results and Discussions

The electrical performance of the commercial 18650 cylindrical type of lithium-ion battery were measured at 0.1C, 0.2C, 0.3C 0.5C, and 1.0C rate. The capacity of the battery is calculated and found to be consistent within the set potnetial and C-rate. The typical discahrge profile of the litium-ion battery at different C-rates are shown in the Figure 3.

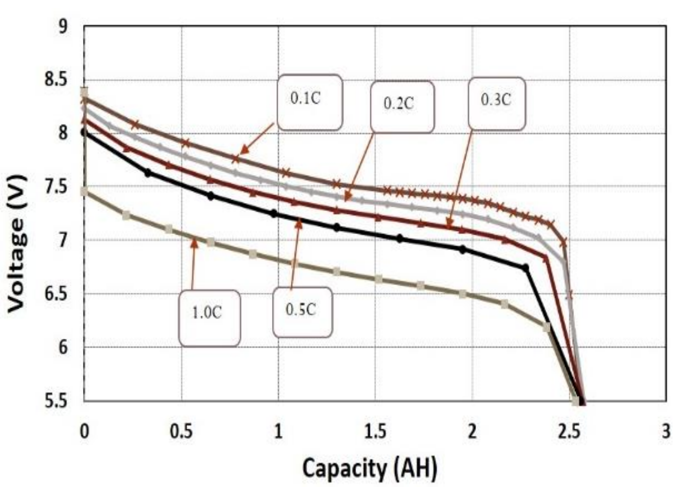

Figure 3: Discharge profiles with different C-rate of the Lithium-ion battery

From the Fig. 3, it is confirmed that the battery pack delivered Electrical and structural analysis reveals that, higher capacity an excellent capacities at different loads. The lithium-ion battery capacities obtained at 0.1C, 0.2C, 0.3C, 0.5C and 1.0C are 98.6%, 98.6%, 98.0%, 98.0% and 96.0% respectively.

It shows that the battery pack deivered highest capacity in the tested potential range at ambient temperature. The capacity of the battery pack at 0.1C and 1.0C were found to be 98.6% and 96.0% respectively.

In general, the safety of the lithium-ion battery under abuse operating and testing conditions are seriously concerned. Further, the large scale capacity of the battery consists of multiple cells connected either in series and parallel configurations to meet the voltage and capacity requirement for the particular applications. Commonly, the lithium-ion battery is integrated with protective circuit or battery management system (BMS) to improve the life of the battery and also safety of the technology as well.

The samples were collected from the battery and then washed out with solvents to remove the trace of impurities in the electrolyte in the powders. The resultant powder was dried out in an oven. X-ray diffraction (XRD) measurement has been carried out using X-ray diffractometer. The XRD spectra were recorded in the range from 10^0 to 70^0 of two theta scale. The spectral analysis were carried out by correlating the experimental data with ICDD/ JCPDS diffraction data. The experimental XRD spectra of the lithium cobalt oxide cathode is shown in the Figure 4.

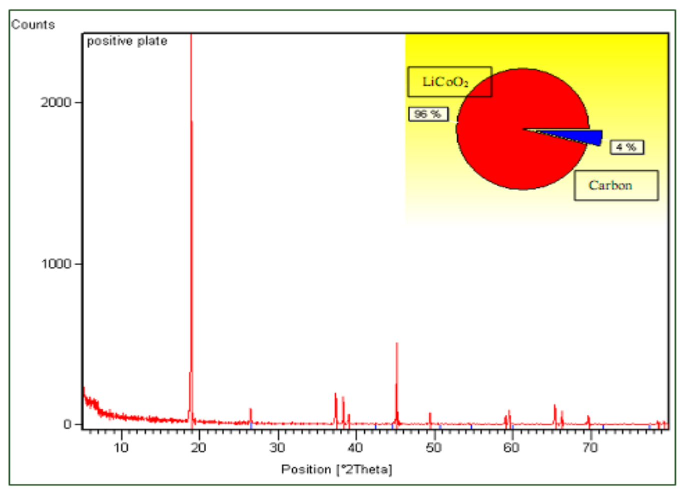

Figure 4: The XRD spectra of lithium cobalt oxide

From the Figure 4, it is clearly noticed that all the reflections are well defined and no impurity phases were observed. The well-defined characteristic (003) reflection clearly indicate the hexagonal/α-$NaFeO_2$ structure. Further, the distribution of active materials of the composite cathode were estimated semi-quantitatively using the in-built software.

The lithium cobalt oxide and the carbon percentage were obtained 96 % and 4% respectively. It suggests that the carbon is added and the presence of small amount of the carbon can improve the electrical properties of the composite cathode. The is obtained even at 1C-rate and also confirmed the chemistry of the cathode and its structure.

The lithium cobalt oxide cathode commonly undergo exothermic reaction under abuse operations and safety is concerned. The safety of the battery is related to materials, nature of electrolyte (liquid, polymer, solid) and also design of the battery. The performance is attributed to the heat generation within the battery and hence future research is focused on the simulation studies to understand the temperature profile of the battery.

4. Conclusions

The lithium-ion battery technology and its unique electrochemical characteristics were addressed. The capacity of 96% was obtained at 1C for the battery tested at ambient temperature. The XRD analysis were confirmed the cobalt oxide as cathode and hexagonal/α-$NaFeO_2$ structure. The lithium-ion battery performance and safety is commonly varied with chemistry to chemistry and also design apart from usage pattern and operating environment as well.

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