Research on Rates Discharge Characteristics of High Energy Density Ternary Lithium Battery

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Abstract. In order to study the effect of rates discharge on characteristics of ternary lithium batteries, a new type of high rate ternary lithium battery from a unit is used as the research object. The discharge test is carried out at the discharge rates of 1C, 4C, 7C, 12C and 15C on this ternary lithium battery at room temperature with high and low temperature charge/discharge test system. The test results show that the energy density under 1C rate discharge is 202.62 Wh/kg. Correspondingly, the energy density under 4C, 7C and 12C rate discharge is 95.17%, 93.83% and 91.79% of the value under 1C rate discharge respectively. Even for 15C rate discharge, its energy density can reach 87.15% of 1C rate discharge. During the discharge process, the temperature of the battery increased with the increase of discharge rate, and the temperature rise at 15C rate by 26 °C.

Keywords: Battery; Ternary lithium; Energy density; Depth of discharge.

1. Introduction

The use of unmanned systems has been increasing in recent years, while the application scenario's are becoming more and more complex and variable, and the requirements for high-power discharge of power batteries have been gradually increasing, so power batteries with high multiplier discharge have become the focus of attention. Lithium-ion batteries are widely used in various portable electronic products and power devices because of their high specific energy, high operating voltage, high power density, long cycle life, ability to charge with various forms of energy, and environmental friendliness [1-3]. When lithium-ion batteries are used in portable electronic devices such as cell phones and laptops, their requirements for battery capacity and output multiplier are small, with a capacity of less than 3Ah and a discharge multiplier of less than 1C [4-5]. However, when lithium-ion batteries are used as a supply power source for power equipment such as ships and electric vehicles, the instantaneous output power of the power battery is required to be doubled in order to ensure the starting and acceleration performance of power equipment such as ships and electric vehicles [6-8]. Yue Zhang [9] et al, found by experiments and studies that when the discharge multiplier of the battery increases, the capacity that can be discharged from the battery decreases and the discharge plateau decreases, making it unstable and causing the battery temperature to rise. If the battery is discharged at a multiplier of 3.0C, the capacity that can be discharged will be reduced to 80%, while the surface temperature rises to 47 °C, a battery with 20C discharge capacity up to 95.1% of 1C discharge capacity; after 300 weeks of 4.5C charging and 9C discharge cycle, the battery capacity still remained above 89%, which has excellent fast charging and high multiplier discharge cycle performance. In general, ternary material is one of the important choices for high rate battery material
because of its excellent cycle performance and other comprehensive performance, so this paper tested a new high rate ternary lithium battery and collected and analyzed its rate characteristics.

2. Experimental Methods

2.1. Test Device and Data Acquisition Platform

The structure of high and low temperature charge/discharge test system is shown in Figure 1. The battery charging and discharging test equipment in the figure is energy recovery type battery test system Chroma 17020, which can test voltage, current, energy, capacity and temperature at the same time, the maximum voltage is 20V, the maximum current is 400A, and the test accuracy is 0.001; the ultra-low temperature environment simulation test chamber is SDJ710FA high and low temperature humidity and heat chamber, the maximum temperature is 150°C, the minimum temperature is -70°C, the accuracy is ±1°C.

![Figure 1. Schematic diagram of the structure of high and low temperature test system.](image)

2.2. Experimental Data Collection Objects

The experimental object is a high rate ternary lithium battery, whose main technical parameters are shown in Table 1.

| Projects                  | Parameters          |
|---------------------------|---------------------|
| Nominal capacity          | 23Ah                |
| Nominal voltage           | 3.7V                |
| Quality                   | 405g±1g             |
| Charge cut-off voltage    | 4.2V                |
| Charge cut-off current    | 1.15A               |
| Max. charging multiplier  | 1C                  |
| Discharge cut-off voltage | 2.8V                |

2.3. Experimental Procedure and Data Collection Content

The battery is connected to the test interface and sampling interface of the battery charge/discharge test equipment through the special battery fixture and sensor, and is discharged in the high and low temperature humidity and heat chamber for different multiplier discharge experiments. During the test,
the battery discharge voltage, charge and discharge current and battery temperature data can be detected, the specific test and data collection as shown in Table 2.

### Table 2. Ternary lithium battery multiplier discharge performance test procedure.

| Steps | Temperature | Experiment content | Data Acquisition |
|-------|-------------|---------------------|------------------|
| 1     | 25°C        | 1C battery discharged to 2.8V and left for 1h | - |
| 2     | 25°C        | Charge to 4.2V with 1C battery and then turn to constant voltage charge to 0.05C and leave for 1h | - |
| 3     | 25°C        | 1C battery discharged to 2.8V and left at room temperature for 1h | Voltage, current, temperature |
| 4     | 25°C        | Charge to 4.2V with 1C battery and then turn to constant voltage charge to 0.05C and leave for 1h | - |
| 5     | 25°C        | 4C battery discharged to 2.8V and left at room temperature for 1h | Voltage, current, temperature |
| 6     | 25°C        | Charge to 4.2V with 1C battery and then turn to constant voltage charge to 0.05C and leave for 1h | - |
| 7     | 25°C        | 7C battery discharged to 2.8V and left at room temperature for 1h | Voltage, current, temperature |
| 8     | 25°C        | Charge to 4.2V with 1C battery and then turn to constant voltage charge to 0.05C and leave for 1h | - |
| 9     | 25°C        | 12C battery discharged to 2.8V and left at room temperature for 1h | Voltage, current, temperature |
| 10    | 25°C        | Charge to 4.2V with 1C battery and then turn to constant voltage charge to 0.05C and leave for 1h | - |
| 11    | 25°C        | 15C battery discharged to 2.8V and left at room temperature for 1h | Voltage, current, temperature |

3. Data Processing and Analysis

3.1. Battery Voltage Data Processing and Analysis

In order to study the effect of discharge multiplier on the battery discharge voltage plateau and depth of discharge, we conducted experiments under the ambient conditions of 25°C. Using the experimental system in Figure 1, we adjusted the discharge multiplier to 1C, 4C, 7C, 12C and 15C, and collected and analyzed the data during the discharge process to obtain the relationship between the discharge voltage and depth of discharge at different discharge multipliers, as shown in Figure 2.
The experimental results showed that the discharge curves at different magnifications were all relatively smooth and reliable in stability, with no abnormalities or abrupt changes. In terms of voltage plateau, relative to the voltage plateau of 1C discharge, the voltage plateau of 4C discharge decreased by 0.15V, the voltage plateau of 7C discharge decreased by 0.25V, the voltage plateau of 14C discharge decreased by 0.4V, and the voltage plateau of 15C discharge decreased by 0.6V; in terms of discharge depth, with the increase of discharge multiplier, the depth of discharge did not change much, and the depth of discharge under 15C discharge condition still reach more than 95% of that under the 1C condition.

Overall the depth of discharge and the discharge voltage plateau both decreased with the increase of the discharge multiplier, in terms of discharge capacity, the overall decreasing trend of the discharge capacity with the increase of the multiplier, the lowest discharge capacity at 15C discharge, still able to reach 94.3% of the rated capacity, but the sudden change at 4C, 7C and 12, showing a rising trend, probably due to the heat generated during the discharge of the battery caused.

3.2. Battery Temperature Rise Data Processing and Analysis

To further study the effect of discharge multiplier on the battery discharge voltage plateau and depth of discharge, we still use the experimental system in Figure 1 to collect the temperature rise data of the battery at different discharge multipliers, respectively. The relationship between battery temperature rise and discharge multiplier is obtained, as shown in Figure 3.
Figure 3. Relationship between battery temperature rise and discharge multiplier.

The experimental results show that the temperature rise of the battery shows a significant upward trend with the increase of the discharge multiplier. When the battery is discharged, the lithium ion undergoes a chemical reaction at both poles and the electrons are embedded and detached in exactly the same amount as the lithium ion, and all the heat generated in the chemical reaction is the heat of the chemical reaction in the battery itself [10-11]. 1C discharges the battery temperature up by 2.2°C, 4C by 8.4°C, 7C is up by 12.9°C, 12C by 20.5°C, and 15C at 25.5°C, further illustrating the abrupt changes seen in the analysis in the previous section, at 4C, 7C and 12C, when the temperature affects the cell to a greater extent than the effect of multiplicity on the cell.

3.3. Energy Density Data Processing and Analysis

In order to study the effect of discharge multiplier on the energy density of the battery, we tested the energy density under different multiplier discharge conditions using the experimental system in Figure 1, and obtained the energy density at different multipliers, as shown in Table 3.

| Discharge multiplier | 1C   | 4C   | 7C   | 12C  | 15C  |
|----------------------|------|------|------|------|------|
| Energy Density (Wh/kg)| 202.52 | 192.74 | 190.32 | 185.88 | 176.50 |

The experimental results show that the energy density decreases significantly with the increase of multiplicity, and the energy density decreases by 4.83% under 4C discharge, 6.02% under 7C discharge, 8.21% under 12C discharge, and 12.85% under 15C discharge. All of them showed a decreasing trend, indicating that the effect of the change in discharge multiplicity was greater than the effect of the change in temperature during the discharge process in terms of energy density.

4. Conclusion

(1) The initial discharge voltage, discharge voltage plateau, depth of discharge and energy density of the battery all decrease with the increase of the discharge multiplier, and the temperature rise of the battery increases with the increase of the discharge multiplier.
(2) When the multiplier is low, the battery's discharge capacity and depth of discharge are more affected by temperature, while the voltage plateau and energy density are more affected by the multiplier.

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