

Effect of Tab Position on Cylindrical Li-ion Battery Performance

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Keywords: Internal resistance; Current collector; 18650-type Li-ion Battery

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Abstract: The calculation formula for thermally equivalent ohmic resistance was based on the calculation of integral ohmic heat of cathode and anode current collector while the tab was in different positions. When changing tab from the side to middle, the current collector resistance decreased to one-quarter, the AC internal resistance of the 18650-type Li-ion battery decreased from 29.37 mΩ to 14.3 mΩ. The discharge voltage plateau increased 0.157 V during 5 C galvanostatic discharge, while temperature rise decreased 8.4 °C. However, it had little effect on low-temperature discharge performance or on low-rate cycle performance at room temperature.

Key words: internal resistance; current collector; 18650-type Li-ion battery

Compared to energy-type lithium-ion batteries used in mobile phones and laptops, power-type lithium-ion batteries exhibit significant advantages in terms of temperature rise performance during high-rate discharge, cycle life under high-rate discharge, and low temperature discharge performance. According to the electrochemical theoretical model of porous electrodes^[1-2], the following measures can be taken to mitigate polarization in lithium-ion batteries under high rate discharge: Reduce electrode thickness to improve the distribution of Li⁺ concentration in the liquid phase; Increase the electrolyte conductivity to enhance the diffusion rate of Li⁺ in the liquid phase; Increase the porosity of cathode, anode and separator to improve the conductivity of both solid and liquid phases; Increase the conductivity of cathode and anode materials or add conductive agents to reduce the resistance of charge transfer between particles; Increase the solid-phase diffusion coefficient of cathode and anode materials to enhance the diffusion rate of Li⁺ in the solid phase; and Select appropriate electrolyte additives to avoid excessively high solid electrolyte interphase (SEI) film impedance. Additionally, the design of tab position is also an important consideration. An appropriate tab position can reduce the ohmic resistance of the battery and lower the temperature rise during high-rate discharge^[3].

The authors of this paper theoretically calculate the current collector resistance of 18650-type lithium-ion batteries with different tab positions and experimentally investigate the effect of tab position on battery performance.

1 Experiment

1.1 Battery Fabrication

A 18650-type lithium-ion battery was fabricated. The cathode current collector was aluminum foil (Hebei Province, China, AR

[Analytical Reagent]) with a thickness of 0.015 mm, and the anode current collector was copper foil (Guangdong Province, China, AR) with a thickness of 0.010 mm. The cathode dimensions were 57 mm in width and 853 mm in length, while the anode dimensions were 58.5 mm in width and 910 mm in length.

The cathode active material was $Li(Ni_{0.5}Co_{0.2}Mn_{0.3})O_2$ ternary material (produced in Tianjin, China, AR), with conductive carbon black SP (from TIMCAL, AR) as the conductive agent and polyvinylidene fluoride (produced in Japan, AR) as the binder; the anode active material was artificial graphite (produced in Shanghai, China, AR), with SP as the conductive agent and sodium carboxymethyl cellulose (produced in Japan, AR) as the binder. According to the company's production process, the steps of slurry mixing, coating, and cutting were carried out. Three types of batteries with different tab positions were designed: *a* with the cathode tab on the inner side and the anode tab at the tail end; *b* with the cathode tab in the middle, and the anode tab at the tail end; *c* with the cathode tab in the middle and the anode tab in the middle. A section was scraped on the electrode sheet using N-methylpyrrolidone (produced in Shandong Province, China, AR) for tab welding, then winding, assembly, and formation of the battery were completed according to the company's production process.

1.2 Battery Performance Testing

The HIOKI3560 Micro-resistance Tester (produced in Japan) was used to measure the battery's AC internal resistance R_{AC} at 2 kHz; the BT2000 Battery Charge/Discharge Tester (produced in the USA) was used for the charge-discharge test; the ESPEC Low-temperature Constant Temperature Chamber (produced in Guangzhou, Guangdong Province, China) was used to provide a low-temperature

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environment.

Rate discharge performance at room temperature: the battery was charged at 1 C (2,000 mA) constant current to 4.2 V, then switched to constant voltage charging until the current drops below 100 mA, next, discharged at the required current, and the surface temperature of the battery was measured.

Low-temperature discharge performance test: the battery was charged at 1 C constant current to 4.2 V, then switched to constant voltage charging until the current drops below 100 mA. It was then placed in a low-temperature chamber, stood at -20 °C for 4 h, then discharged with 1 C and 5 C pulse currents for 1 s each, repeating the cycle 3 times to test the DC resistance R_{DC} of the battery, and then discharged at the required current at low temperature.

Cycle life test at room temperature: the battery was charged at 1 C constant current to 4.2 V, then switched to constant voltage charging until the current drops below 100 mA, then discharged at 5 C to 2.5 V.

2 Results and Discussion

2.1 Relationship Between Tab Position and AC Internal Resistance

The distribution of current on the current collector is shown in Figure 1. All external current flows in through the tab. It is assumed that the current flowing out from each segment $x_1, x_2 \dots x_n$ is approximately equal, that is, the rate of Li^+ intercalation and deintercalation on the electrode in the length direction is approximately uniform.

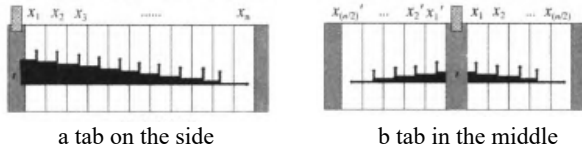


Figure 1. Current distribution on conductive foil

When the tab is on one side, the current distribution on the current collector is shown in Figure 1a. The current flowing out from the farthest end from the tab at x_n needs to pass through the preceding segments: x_1-x_n ; the current flowing out from the x_3 segment needs to pass through: $x_1-x_2-x_3$ segments... The external discharge current is I , and the reaction current per segment is I_a . Then, the current flowing through the x_1 segment of the current collector is $n \cdot I_a$; the current flowing through the x_2 segment of the current collector is $(n-1) \cdot I_a$; the current flowing through the x_3 segment of the current collector is $(n-2) \cdot I_a$; and the current flowing through the x_n segment of the current collector is I_a .

For each segment of the current collector, the ohmic heat generated as current passes through the current collector was calculated.

$$Q_i = I_i^2 \cdot R_i \cdot t \quad (1)$$

$$R_i = \rho \cdot dx / A \quad (2)$$

In equations (1) and (2): ρ is the resistivity of the current collector, dx is the length of each segment, and A is the cross-sectional area of the current collector. The total heat Q on the current collector may be calculated using equations (3)–(5), and the thermally equivalent ohmic resistance R on the current collector may be determined.

$$Q = Q_1 + Q_2 + \dots + Q_n \quad (3)$$

$$I^2 R t = \left[\left(\frac{I}{n} \right)^2 t + \left(\frac{2I}{n} \right)^2 t + \dots + \left(\frac{nI}{n} \right)^2 t \right] \cdot \frac{\rho L}{nS} \quad (4)$$

$$R = \lim_{n \rightarrow \infty} \frac{2n^3 + 3n^2 + n}{6n^3} \cdot \frac{\rho L}{S} = \frac{\rho L}{3S} \quad (5)$$

When the tab is in the middle of the electrode sheet, the current distribution on the current collector is shown in Figure 1b. Similarly, the thermally equivalent ohmic resistance of the current collector was calculated by heat integration.

$$Q = 2(Q_1 + Q_2 + \dots + Q_{n/2}) \quad (6)$$

$$I^2 R t = 2 \left[\left(\frac{I}{n} \right)^2 t + \left(\frac{2I}{n} \right)^2 t + \dots + \left(\frac{nI}{2n} \right)^2 t \right] \cdot \frac{\rho L}{nS} \quad (7)$$

$$R = \lim_{n \rightarrow \infty} \frac{n^3 + 3n^2 + 2n}{12n^3} \cdot \frac{\rho L}{S} = \frac{\rho L}{12S} \quad (8)$$

By comparing equations (5) and (8), it can be seen that when the tab is located in the middle, the current collector resistance is only 1/4

of that when it is on one side. For a given electrode width, the current collector resistance is proportional to its length. This differs from the fact that the degree of polarization during electrochemical reactions is inversely proportional to the electrode length. Based on this, it can be inferred that there is an optimal value for the electrode length in terms of the battery resistance.

At 25 °C, the resistivity of aluminum is $2.94 \times 10^{-8} \Omega \cdot \text{m}$, and the resistivity of copper is $1.76 \times 10^{-8} \Omega \cdot \text{m}$. Using equations (3) and (6), the current collector resistance was calculated, and the actual R_{AC} of the battery was measured. The results are shown in Table 1.

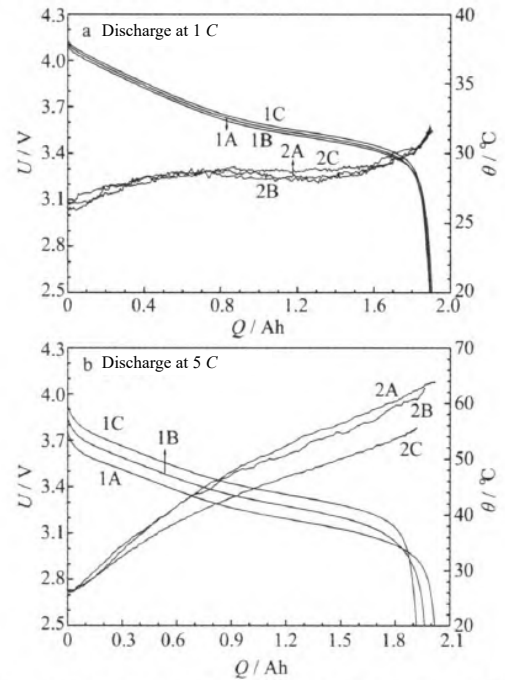
Table 1. Calculated current collector resistance and tested battery resistance of different tab position

Tab Position	Calculated Resistance/mΩ			Tested R_{AC} /mΩ
	Aluminum Foil	Copper Foil	Sum of Aluminum Foil and Copper Foil	
a	9.78	9.12	18.90	29.37
b	2.44	9.12	11.56	21.51
c	2.44	2.28	4.72	14.30

The current collector resistance accounts for a relatively large proportion of the total battery resistance. As shown in Table 1, the calculated difference in current collector resistance between Design a and Design b is 7.34 mΩ, while the measured R_{AC} difference is 7.86 mΩ; the calculated difference in current collector resistance between Design a and Design c is 14.18 mΩ, while the measured R_{AC} difference is 15.07 mΩ. The theoretical calculation results align well with the measured differences, indicating that it is reasonable to calculate the current collector resistance of lithium-ion batteries using the thermally equivalent ohmic resistance. The key to calculating the current collector resistance lies in establishing the current distribution on the current collector.

2.2 Rate Discharge Performance at Room Temperature for Batteries with Different Tab Positions

The rate discharge performance of batteries with three different tab positions, namely a, b, and c, is shown in Figure 2.



1: Voltage; 2: Temperature; A: a tab position; B: b tab position; C: c tab position

Figure 2. Rate discharge performance at room temperature of batteries with 3 kinds of tab position

As shown in Figure 2, the voltage plateaus of the three battery types show minimal difference during 1 C discharge; However, during 5 C discharge, corresponding to the resistance of their current collectors, the voltage plateaus rank from highest to lowest as c, b, and a; Concurrently, since the temperature rise during discharge of structures a, b, and c decreases in the order $a > b > c$, the discharge capacities of the batteries also rank from highest to lowest as a, b, and c.

2.3 Low-Temperature Discharge Performance of Batteries with Different Tab Positions

The R_{DC} test results of batteries with three tab positions at -20°C are shown in Figure 3.

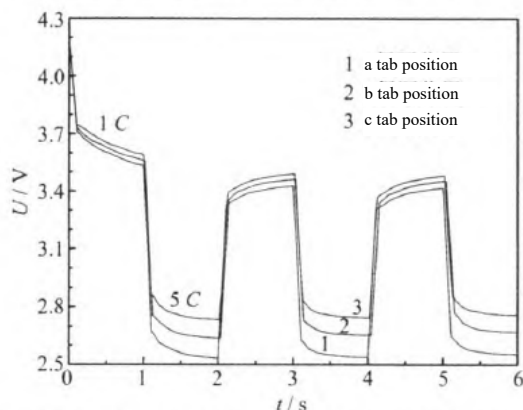


Figure 3. R_{DC} test results of batteries with 3 kinds of tab position at -20°C

During a certain pulse, the R_{DC} at low temperature is obtained by dividing the voltage difference between 1 C and 5 C by their current difference. As shown in Figure 3, during the second pulse, the R_{DC} at -20°C for batteries with tab positions a, b, and c are $99.8\text{ m}\Omega$, $91.6\text{ m}\Omega$, and $82.1\text{ m}\Omega$, respectively. This indicates that at low temperatures, the current collector resistance accounts for only a small portion of the total battery resistance.

The galvanostatic discharge test results of batteries with three tab positions at -20°C are shown in Figure 4.

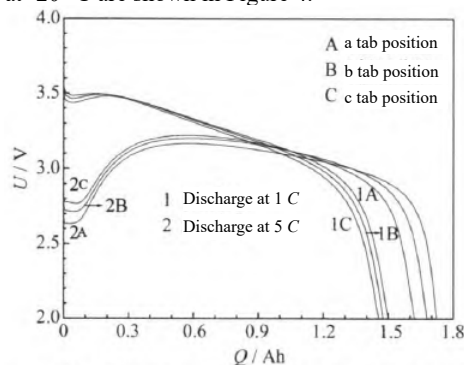


Figure 4. Galvanostatic discharge curves of batteries with three tab positions at -20°C

As shown in Figure 4, during the initial stage of low-temperature discharge, the voltage drop of the battery corresponds to the R_{DC} due to differences in current collector resistance caused by the tab position; As the discharge proceeds, the battery with tab position a generates more heat, leading to an increase in battery temperature. The current density on the current collector near the tab is higher, resulting in significant ohmic heating in this area, and the temperature rises faster here than in other areas. According to the porous electrode electrochemical model, the relationship between temperature and solid-phase electronic conductivity, liquid-phase ionic conductivity, solid-phase diffusion coefficient, liquid-phase diffusion coefficient, and electrochemical reaction rate can be described by the Arrhenius equation^[4], thereby establishing the coupled equations for electrochemistry and heat conduction. Overall, since the tab position a generates more heat during discharge, it releases more capacity at low temperatures. Simultaneously, since discharging at 5 C produces more heat than discharging at 1 C , this results in the release of more capacity at 5 C discharge compared to 1 C discharge.

2.4 Cycle Performance of Batteries with Different Tab Positions

The cycle performance test results of batteries with different tab positions are shown in Figure 5.

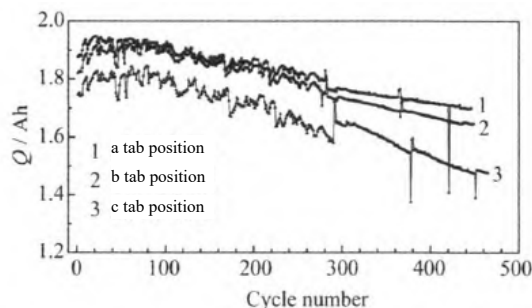


Figure 5. 5 C discharge cycle life of batteries with three tab positions

As shown in Figure 5, the cycle life of batteries with tab positions a and b is slightly longer than that of battery with tab position c. However, the overall difference is small, and it does not correspond with the resistance test results. This contradicts the common understanding that reduced resistance should correspondingly extend cycle life. The reason lies in the relationship between battery temperature rise and lifespan, where the battery's temperature is determined by the heat generated during discharge and the rate of heat exchange with the external environment. The heat generated during battery discharge originates from three components: ohmic heat, polarization heat, and chemical reaction heat^[4]. During high-current discharge, ohmic heat and polarization heat account for a higher proportion, whereas during low-current discharge, chemical reaction heat constitutes a larger share. The designed battery is a power-type battery. When discharged at 5 C , the battery surface temperature remains below 65°C , and the tab structure has little effect on the cycle life, indicating that the tab structure has minimal effect on the cycle life under low-current discharge.

3 Conclusion

The tab position can significantly alter the R_{AC} of the battery and allow for quantitative calculation of its effect on R_{AC} . The tab position has a limited effect on low-temperature discharge performance, but it notably alters the high-rate discharge capability and high-current cycling performance of the battery. The measurement of R_{AC} does not alter the electrochemical state of the electrode. During high-rate discharge, a coupled process involving electrochemical and heat transfer equations occurs, and the current distribution across the electrode changes due to uneven temperature distribution. However, R_{AC} cannot reflect this process. Therefore, overall, an appropriate tab position distribution reduces the equivalent resistance of the current collector to a very low level. Adding more tabs contributes little to R_{AC} but helps alter the current and temperature distribution under dynamic conditions, thereby benefiting the high-rate discharge performance and high-rate cycle performance of the battery.

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Date of Receipt: March 18, 2015



DECLARATION OF TRANSLATOR

I, Johnson Wong, hereby declare as follows:

1. I personally performed the attached translation from Chinese into English of the patent that is entitled “Mo paper” in Chinese and “Mo paper_English” in English (also attached).

2. The attached translation is, to the best of my knowledge, a true, full and accurate translation of the attached Chinese document.

3. I am competent to perform this translation, because I have a ***Bachelor of Engineering Physics and over twenty years’ experience in technical Chinese-to-English translations.***

4. I declare under the penalty of perjury under the laws of the United States that the foregoing is true and correct; and further declare that I am aware that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 1001 of Title 18 of the United States Code.

Dated: May 12, 2026

TRANSLATORS’ SIGNATURE

A handwritten signature in black ink, appearing to read "Johnson Wong", written over a horizontal line.

(Bibliographic information, abstract, specifications)

(Claims, drawings)

极耳位置对圆柱形锂离子电池性能的影响

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摘要:计算不同极耳位置对正负极集流体积分欧姆热量的影响,推导集流体热等效欧姆电阻的计算公式。极耳在极片中间时,集流体内阻仅为在一侧时的1/4。将极耳由侧边改到中间,18650型锂离子电池的交流内阻由29.37 m Ω 降至14.3 m Ω ,常温下5 C的放电电压平台提高0.157 V,且温升降低8.4 $^{\circ}\text{C}$,但对低温放电性能、常温下较小倍率循环的影响很小。

关键词:内阻; 集流体; 18650型锂离子电池

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Abstract: The calculation formula for equivalent ohmic heat resistance was based on the calculation of integral ohmic heat of cathode and anode current collector while the tab was in different positions. When changing tab from the side to middle, the current collector resistance decreased to the one quarter, the AC impedance of 18650 type Li-ion battery decreased from 29.37 m Ω to 14.3 m Ω . The discharge voltage platform increased 0.157 V during 5 C galvanostatic discharge, while temperature rise decreased 8.4 $^{\circ}\text{C}$. But it only made a little improvement both its low temperature discharge and low rate cycle performance at room temperature.

Key words: impedance; current collector; 18650 type Li-ion battery

相比于手机和笔记本电脑用能量型锂离子电池,功率型锂离子电池在大倍率放电时的温升性能、大倍率放电的循环寿命及低温放电性能方面优势明显。根据多孔电极的电化学理论模型^[1-2],为了减轻锂离子电池在高倍率放电下的极化,可采取以下几种措施:降低极片厚度,以改善液相的Li⁺浓度分布;增大电解液的电导率,以提高Li⁺在液相的扩散速率;增大正极、负极、隔膜孔隙率,以提高固相、液相的电导率;提高正极、负极材料的电导率或增加导电剂,以降低电荷在颗粒间的传导电阻;提高正极、负极材料的固相扩散系数,以提高固相的Li⁺扩散速率;选择合适的电解液添加剂,避免过高的固体电解质相界面(SEI)膜阻抗。另外,极耳位置的设计也是很重要的内容,合适的极耳位置能降低电池的欧姆内阻,并降低电池大倍率放电时的温升^[3]。

本文作者从理论计算不同极耳位置的18650型锂离子

电池集流体内阻,并测试极耳位置对电池性能的影响。

1 实验

1.1 电池制作

制作18650型锂离子电池,正极集流体铝箔(河北产,AR)的厚度为0.015 mm,负极集流体铜箔(广东产,AR)的厚度为0.010 mm,正极宽度为57 mm、负极宽度为58.5 mm,正极长度为853 mm、负极长度为910 mm。

正极活性物质为Li(Ni_{0.5}Co_{0.2}Mn_{0.3})O₂三元材料(天津产,AR),以导电炭黑SP为导电剂(特密高公司,AR),聚偏氟乙烯(日本产,AR)为粘结剂;负极活性物质为人造石墨(上海产,AR),以SP为导电剂,羧甲基纤维素钠盐(日本产,AR)为粘结剂。按本公司的生产工艺,进行匀浆、涂覆、剪切。设计3种极耳位置的电池:a为正极耳在里侧,负极耳在

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尾部;b为正极耳在中间,负极耳在尾部;c为正极耳在中间,负极耳在中间。用N-甲基吡咯烷酮(山东产,AR)在极片上刮开一块,用于极耳焊接,并按本公司生产工艺,完成电池的卷绕、装配及活化。

1.2 电池性能测试

用HIOKI3560微电阻测试仪(日本产)测试电池2 kHz的交流内阻 R_{AC} ;用BT2000电池充放电仪(美国产)进行充放电测试;用ESPEC低温恒温箱(广州产)提供低温环境。

电池的常温倍率放电性能:以1 C(2 000 mA)恒流充电到4.2 V,转恒压充电至电流小于100 mA,以要求的电流进行放电,并测量电池的表面温度。

低温放电性能测试:以1 C恒流充电到4.2 V,转恒压充电至电流小于100 mA,置于低温箱中,在-20℃下静置4 h,然后分别以1 C、5 C脉冲电流各放电1 s,循环3次,测试电池的直流内阻 R_{DC} ,再以要求的电流对电池进行低温放电。

常温循环寿命测试:以1 C恒流充电到4.2 V,转恒压充电至电流小于100 mA,再以5 C放电到2.5 V。

2 结果与讨论

2.1 极耳位置与交流内阻的关系

电流在集流体上的分布见图1,外部的电流全部流经极耳而来,认为从 $x_1, x_2 \dots x_n$ 每一段流出的电流是近似相等的,即在极片长度方向上,电极上 Li^+ 嵌脱的速度近似相等。

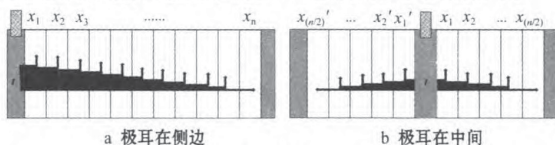


图1 集流体的电流分布

Fig. 1 Current distribution on conductive foil

极耳在一侧时,电流在集流体上的分布见图1a。离极耳最远端的 x_n 处流出的电流,需要经过前面的 $x_1 - x_n$ 段, x_3 段流出的电量需要经过 $x_1 - x_2 - x_3$ 段……,外部放电电流为 I ,每一段的反应电流为 I_n ,则流经 x_1 段集流体的电流为 $n \cdot I_n$,流经 x_2 段集流体的电流为 $(n-1) \cdot I_n$,流经 x_3 段集流体的电流为 $(n-2) \cdot I_n$,流经 x_n 段的集流体的电流为 I_n 。

对集流体的每一段,计算电流经过集流体的欧姆热量。

$$Q_i = I_i^2 \cdot R_i \cdot t \quad (1)$$

$$R_i = \rho \cdot dx / A \quad (2)$$

式(1)、(2)中: ρ 为集流体的电阻率, dx 为每一段的长度, A 为集流体的横截面积。可由式(3)-(5)计算在集流体上的总热量 Q ,计算在集流体上的热等效内阻 R 。

$$Q = Q_1 + Q_2 + \dots + Q_n \quad (3)$$

$$I^2 R t = \left[\left(\frac{I}{n} \right)^2 t + \left(\frac{2I}{n} \right)^2 + \dots + \left(\frac{nI}{n} \right)^2 \right] \cdot \frac{\rho L}{nS} \quad (4)$$

$$R = \lim_{n \rightarrow \infty} \frac{2n^3 + 3n^2 + n}{6n^3} \cdot \frac{\rho L}{S} = \frac{\rho L}{3S} \quad (5)$$

极耳在极片中间时,电流在集流体上的分布见图1b。同样,利用热量积分计算集流体等效热内阻。

$$Q = 2(Q_1 + Q_2 + \dots + Q_{n/2}) \quad (6)$$

$$I^2 R t = 2 \left[\left(\frac{I}{n} \right)^2 t + \left(\frac{2I}{n} \right)^2 + \dots + \left(\frac{nI}{2n} \right)^2 \right] \cdot \frac{\rho L}{nS} \quad (7)$$

$$R = \lim_{n \rightarrow \infty} \frac{n^3 + 3n^2 + 2n}{12n^3} \cdot \frac{\rho L}{S} = \frac{\rho L}{12S} \quad (8)$$

对比式(5)、(8)可知,极耳位于中间时,集流体的内阻仅为在一侧时的1/4,在电极宽度一定时,集流体内阻与长度成正比。这与电化学反应时极化程度与电极长度成反比不同。据此推断,电极的长度对电池内阻而言有一个最优值。

在25℃时,铝的电阻率为 $2.94 \times 10^{-8} \Omega \cdot \text{m}$,铜的电阻率为 $1.76 \times 10^{-8} \Omega \cdot \text{m}$ 。利用式(3)及式(6)计算集流体的内阻,并测量实际电池的 R_{AC} ,结果见表1。

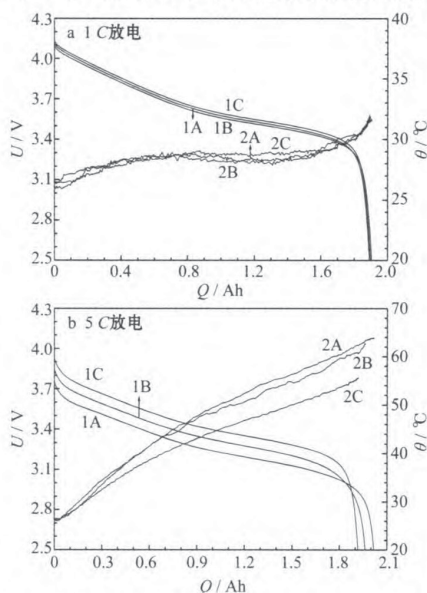
表1 不同极耳位置的集流体内阻计算值与电池内阻实测值
Table 1 Calculated current collector resistance and tested battery resistance of different tab position

极耳位置	计算内阻/mΩ			实测 R_{AC} /mΩ
	铝箔	铜箔	铝箔与铜箔之和	
a	9.78	9.12	18.90	29.37
b	2.44	9.12	11.56	21.51
c	2.44	2.28	4.72	14.30

集流体内阻占整个电池的较大比重。从表1可知,计算所得设计a与设计b之间的集流体内阻差异为7.34 mΩ,实测 R_{AC} 差异为7.86 mΩ;计算所得设计a与设计c之间的集流体内阻差异为14.18 mΩ,实测 R_{AC} 差异为15.07 mΩ。理论计算的差异与实测差异结果吻合,说明用热等效内阻计算锂离子电池集流体内阻是合理的,计算集流体内阻的关键,是建立集流体上的电流分布。

2.2 不同极耳位置电池的常温倍率放电性能

a、b和c等3种极耳位置的电池倍率放电性能见图2。



1 电压 2 温度 A a极耳位置 B b极耳位置 C c极耳位置

图2 3种极耳位置电池常温倍率放电性能

Fig. 2 Rate discharge performance at normal temperature of batteries with 3 kinds of tab position

从图2可知,1 C放电时3种电池的电压平台差异很小;而5 C放电时,与3种电池的集流体内阻对应,电压平台从高到低依次为c、b和a;同时,由于a、b和c这3种结构在放电时的温升从大到小依次为a、b和c,导致电池的放电容量从高到低依次为a、b和c。

2.3 不同极耳位置电池的低温放电性能

3种极耳位置电池的-20℃ R_{DC} 测试结果见图3。

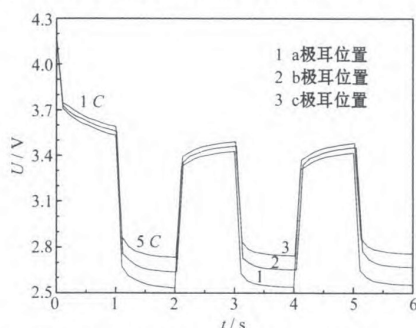


图3 3种极耳位置电池-20℃时的 R_{DC} 测试结果

Fig.3 R_{DC} test results of batteries with 3 kinds of tab position at -20 °C

在某次脉冲时,1 C与5 C的电压差除以二者的电流差,即可得到低温下的 R_{DC} 。从图3可知,在第2次脉冲时,a、b和c等3种极耳位置电池-20℃时的 R_{DC} 分别为99.8 mΩ、91.6 mΩ和82.1 mΩ。由此可见,低温下集流体内阻只占整个电池内阻的较小部分。

3种极耳位置电池-20℃时的恒流放电测试结果见图4。

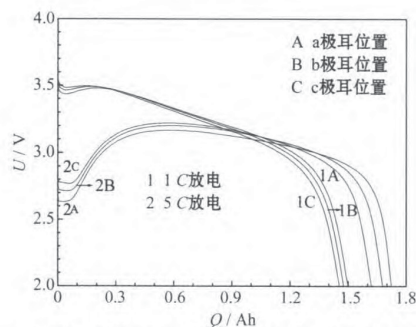


图4 3种极耳位置电池-20℃时的恒流放电曲线

Fig.4 Galvanostatic discharge curves of batteries with 3 kinds of tab position at -20 °C

从图4可知,低温放电初始阶段,由于极耳位置导致的集流体内阻差异,电池的电压降与 R_{DC} 对应;随着放电的进行,a极耳位置的电池产生更多的热量,电池温度升高,靠近极耳的地方集流体上的电流密度大,此处的集流体欧姆热大,温度升高比别处更快。根据多孔电极电化学模型,固相电子电导率、液相离子电导率、固相扩散系数、液相扩散系数、电化学反应速率与温度之间的关系可由Arrhenius公式表示^[4],从而建立电化学与热传导的耦合方程。总体而言,因为a极耳位置放电时产生更多的热量,所以a极耳位置在低温下放出更多的容量,同时,由于5 C放电比1 C放电产生

更多的热,导致5 C放电反而比1 C时放出更多的容量。

2.4 不同极耳位置电池的循环性能

不同极耳位置电池的循环性能测试结果见图5。

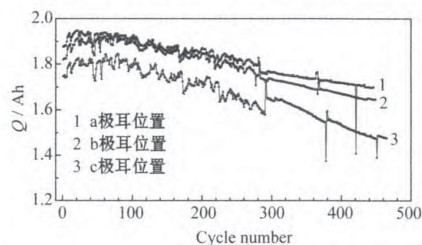


图5 3种极耳位置电池的5 C放电循环寿命

Fig.5 5 C discharge cycle life of batteries with 3 kinds of tab position

从图5可知,a、b极耳位置的电池略长于c极耳位置的电池,但总体而言差异较小,且与内阻测试结果没有对应关系。这与通常理解的内阻减小循环寿命相应延长不符,原因是电池的温升与寿命相关,而电池的温度决定于放电时产生的热量及电池与外界热交换的速度。电池放电时的热量来源于欧姆热量、极化热量和化学反应热3个部分^[4],大电流放电时,欧姆热和极化热所占比例较高,而小电流放电时化学反应热所占比例较高。设计的电池为功率型电池,5 C放电时,电池表面温度低于65℃,极耳结构对循环寿命的影响不大,说明极耳结构对小电流放电的循环寿命影响很小。

3 结论

极耳位置能显著改变电池的 R_{AC} ,并可定量计算对 R_{AC} 的影响。极耳位置对低温放电的影响不大,但明显改变了电池的高倍率放电性能和大电流循环性能。 R_{AC} 的测量不会改变电极的电化学状态,而在大倍率放电过程中,将发生电化学和热传导方程的耦合过程,极片上的电流分布将因为各点温度不均而发生变化,但 R_{AC} 不能反映这一过程,因此总体而言,合适的极耳位置分布让集流体上的等效内阻降低到很低的程度,再用更多的极耳,对 R_{AC} 的贡献很小,但有利于改变电池在动态下的电流、温度分布,从而有利于电池的高倍率放电性能和高倍率循环性能。

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