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Short communication

Comparison of chronoamperometric response and rate-performance of porous insertion electrodes: Towards an accelerated rate capability test

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HIGHLIGHTS

- Advanced analysis of rate performance using chronoamperometry (CA) based method.
- Excellent agreement between conventional rate capability tests (CRCT) and CA-method.
- CA-method is much more straightforward and significantly faster compared to CRCT.

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ABSTRACT

The rate performance of secondary batteries is one of the key factors to push these technologies towards large-scale applications such as hybrid- and all-electric vehicles. Common test procedures, to evaluate the rate capability of novel active materials, electrodes, cells and complete batteries, provide indispensable information but are very time consuming. In the present study, a straightforward and timesaving experimental approach to determine the rate capability of porous insertion electrodes for Li-ion batteries is proposed. The chronoamperometric response of various electrodes with different active materials and design parameters is compared with conventional rate capability tests using a straightforward mathematical conversion approach. The experimental results clearly show that the rate performance can be deduced accurately from the chronoamperometric measurements. The theoretical evaluation of a straightforward equivalent circuit model also indicates an equivalence of the information contained in the conventional rate capability tests and the chronoamperometric response, which supports the experimental findings. The presented approach provides similar information compared to conventional rate capability tests with the benefits of being much more straightforward and significantly faster.

1. Introduction

At the present day, Li-ion batteries (LIBs) are widely used in portable consumer electronics and become increasingly attractive in the automotive industry [1–3]. To increase the power density and push LIBs towards such large-scale applications, one of the most important parameters to be improved is the maximum charge/discharge current [4–6]. A high rate capability could even compensate for a low theoretical capacity. For example, the ultra-fast charging of an electric vehicle during short, inevitable stops might increase the user acceptance, even though the maximum range without charging remains relatively low. Therefore, common test procedures to evaluate the electrochemical performance of novel active materials, electrodes, cells, and batteries include so called rate capability tests. Therein, a cell is charged/discharged at different specific currents (e.g. in A g^{-1} or h^{-1}), while recording the attained capacity (cf. Fig. 1). For example, in a common discharge rate capability test, a cell is first charged at a low rate (e.g. C/10) to the upper cutoff voltage using a constant-current/constant-voltage procedure. Afterwards, the cell is discharged at a specific current until the lower cutoff potential is reached. This procedure is repeated several times to ensure a certain statistical accuracy and to monitor any possible degradation effects. The whole procedure is repeated for different discharge rates. The capacity is determined by the integration of the current and plotted against the discharge rate. Such test procedures provide indispensable information about the rate performance but can be extremely time consuming. Depending on the desired resolution and statistical accuracy, the duration of a rate capability test (charge, discharge, and data analysis) varies between 10 and 40 days. Therefore,

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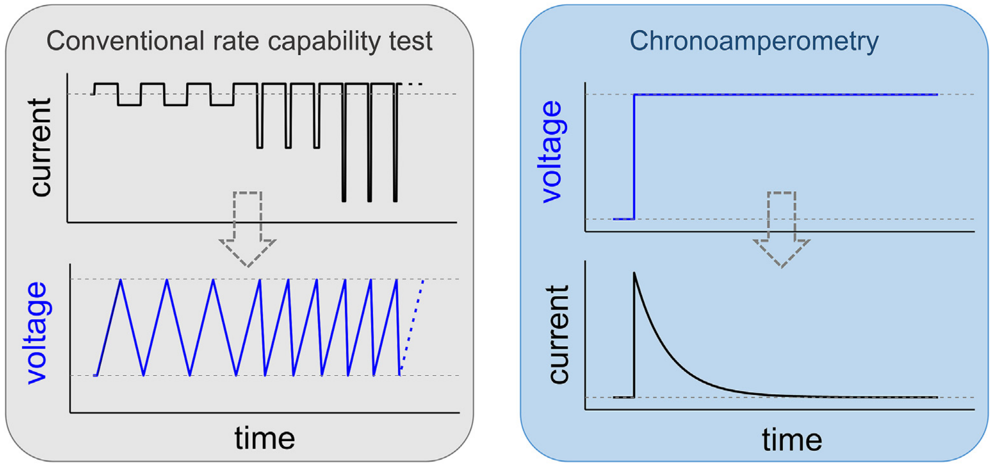

Fig. 1. Schematic illustrations of experimental procedures. Left: conventional rate capability test. Right: chronoamperometry.

alternative experimental approaches to evaluate the rate performance of novel active materials, electrodes, cells and batteries would be highly beneficial.

The fastest way to charge or discharge a battery in a certain voltage range (e.g. 3.0–4.2 V) is the chronoamperometric method [7,8]. For example, at the fully charged state, e.g. at a cell voltage of 4.2 V, the application of 3.0 V causes an electric current until the open circuit voltage of the cell is equal to 3.0 V [9] (cf. Fig. 1). For the time, $t \rightarrow \infty$, the attained capacity will be identical to the nominal capacity. In the case of $t < \infty$ the attained capacity is smaller than the nominal value, depending on the actual value of t and the rate of the cell reaction (electric current). For example, in the case of very low values for t and low reaction rates (electric currents), the attained capacity will be small compared to the nominal capacity. In this sense, the measured current transient contains information about the rate capability of the cell. However, chronoamperometry is rarely used in battery research. The existing studies apply chronoamperometric methods to address specific issues related to interfacial kinetics [10–12] and diffusion phenomena [13–15].

Herein, we propose a straightforward and timesaving experimental approach to determine the rate capability of porous insertion electrodes for LIBs based on chronoamperometry. The current transients of various electrodes with different active materials and design parameters are compared with conventional rate capability tests using a straightforward mathematical conversion approach.

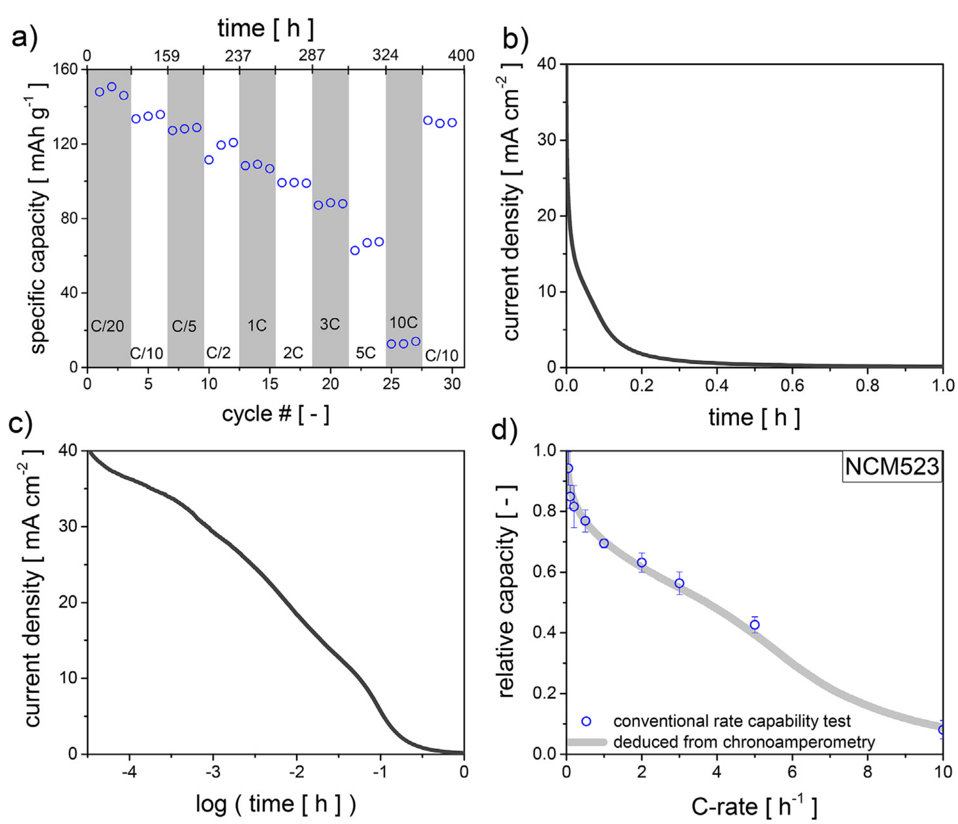

Fig. 2. a) Conventional rate capability test applied to the NCM523-electrode, b) and c) current transient obtained by the application of a potential step to 3.0 V, and d) comparison of the rate performance obtained by the conventional rate capability test and by the evaluation of the chronoamperometric response.