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Production of large-area lithium-ion cells – Preconditioning, cell stacking and quality assurance

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ABSTRACT

In times of climate change and shortage of fossil fuels, electro mobility provides a clean and sustainable solution. The growing number of electric vehicles generates a huge demand on lithium-ion cells. Due to higher quality requirements and different conditions of operation compared to consumer cells adapted production processes and systems are needed. Consequently, this paper analyses the process chain for lithium-ion cells and proposes solutions for the automation of important process steps suitable for mass production, in particular the pre-conditioning of the electrodes and the cell stacking. Additionally, an approach for the detection of particles on electrode surfaces is presented.

1. Introduction

The reduction of greenhouse gas (GHG) emissions is the answer of most governments to climate change. Furthermore, alternatives for fossil fuel applications need to be found due to its future shortage. In terms of vehicles for individual mobility, the substitution of the internal combustion engine (ICE) by an electric drive train provides a solution for both issues [1]. On the one hand, battery electric vehicles (BEV), like the MUTE shown in Fig. 1, do not emit GHG.

On the other hand, the high well-to-wheel efficiency of electric vehicles reduces the carbon footprint. If a BEV is charged with electricity entirely made from renewable energy sources, there will be no GHG emissions at all in the utilization phase of the vehicle. Consequently, electric mobility is promoted in many countries, so that automobile OEMs have begun to include electric vehicles, such as BEVs, in their product ranges. The increasing number of electric vehicles in these days and the prospective market penetration leads to an enormous demand in energy storage solutions for electric vehicles. Focusing on BEVs, lithium-ion technology will be the preferred solution for this decade, mainly motivated by the energy density provided by corresponding battery systems. Nevertheless, current automotive lithium-ion battery systems store approximately two magnitudes less energy than fuel tanks of medium-sized ICE vehicles. Cell manufacturers have proclaimed a target value for the specific energy of lithium-ion cells of about 250 Wh/kg. Despite electrochemical improvements, it is a production engineering challenge to increase the energy density of the cells. In general, large lithium-ion cells are predicted to be the first choice for automotive applications, since they provide higher energy densities accompanied with fewer assembly operations on battery level. The energy density of the cell is influenced by the coating parameters, the cell assembly process and the cell housing. This paper focuses on the cell assembly, which entails several challenges in the field of process design, preconditioning as well as quality assurance. Chapter 2 compares the available variants of large lithium-ion cells and their properties. The process chain for large lithium-ion cells is detailed in chapter 3, which provides the basics for the following chapters focusing on single process steps and quality measures investigated at the *iwb*.

2. Variants of large lithium-ion cells

In the field of large lithium-ion cells three major cell types can be distinguished: the cylindrical cell, the pouch cell and the prismatic cell [2], see Fig. 2.

Cylindrical cells are the most common cell type in the field of small lithium-ion cells, used for instance in consumer applications. Even though there are examples for BEVs using small cylindrical cells (e.g. Tesla), the high assembly effort for a battery system suitable for automotive applications accompanied with the low packing density lead to the application of large lithium-ion cells in the future. Independent of the size of cylindrical cells, their production is performed with the help of winding machines. Consequently, the profound experience gained with the production of the small cells in the last decades can be applied for automotive cells, leading to reliable and economic manufacturing processes. The housing of large cylindrical cells, as well as of prismatic cells, is a deep-drawn metal can, e.g. aluminum, or an injection molded plastic case. Thereby, the cover of a hard case cell presents a multifunctional component providing the interface to the cell stack and to the battery system, a safety vent and the leak tightness of the cell. Due to their hard cases cylindrical cells as well as prismatic cells are considered as quite safe and thus chosen by most automobile OEMs for their batteries. On the other hand, pouch cells are arrangements of electrodes and separator layers

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Fig. 1. MUTE–BEV of the Technische Universität München.

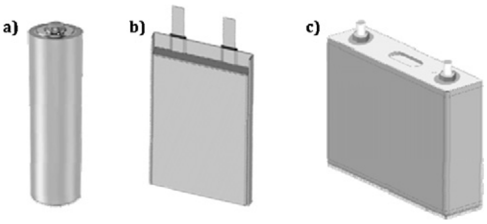

Fig. 2. Lithium-ion cell types: (a) cylindric cell, (b) pouch cell, and (c) prismatic cell [3].

packed in a compound-foil, which usually consists of aluminum and polyolefin layers. In small numbers this cell type is easy to build in laboratories without the need of significant investments in production facilities. Consequently, most research institutes and start-ups currently focus on pouch cells. Nevertheless, this cell type is an interesting option for automotive applications due to its high energy density, especially resulting from the substitution of the hard case, and a high freedom in the design of the battery system, e.g. in case of the heat management. An issue to be solved is the leak tightness of the pouch cells in the area of the bond between the compound foil and the conductors. A possible solution is the pretreatment of the metal surfaces, as described in [4]. Both the pouch cells as well as the prismatic cells provide a higher packing density on battery system level than cylindrical cells, which is a direct consequence of the geometry standards in most applications.

3. Cell manufacturing processes

During cell manufacturing, four phases are well defined (Fig. 3) [5].

First, in the electrochemical affected process steps, basic materials such as anode and cathode active materials, electrolytes, additives and binder are confected. These materials determine the electrical and chemical properties of the cells.

In the second phase, wrought materials are manufactured. Anode and cathode coils are produced using coating processes. The active materials, mixed up in solvent, are coated on aluminum (for the cathodes) or copper (for the anodes) foils. After the coating, the active layer is heated in order to dry out the solvent and to fix the coating on the foils by means of the binder. Additionally to the electrode coils, the separator has to be produced. Normally this is a porous polyolefin foil with an average thickness of 20 microns. Not least, other components of the cells have to be made, e.g. the cell housings.

In the third phase, the cell is assembled. The central process is the building of the cell stack whereat the alternating arrangement of anode, separator and cathode layers is composed. Three fundamentally different cell stacking methods exist that differ in the way of processing the electrode and separator materials. Whereas single sheet stacking uses single electrodes as well as single separator sheets, winding technologies (cylindrical or prismatic) process continuous materials. z-Folding processes, as the third variant, can use either continuous electrodes and separator or only continuous separator combined with single electrode sheets [6]. Cell stacking technologies that use single electrode foils require preconditioning of the electrodes by mechanical or laser cutting. After the stack is built up the cell is finally assembled by joining the current collectors, housing the cell stack in compound foil or aluminum cases, filling the cell with electrolyte and sealing the cell housing. In this stage, water-free production is a very important issue. Thus, cell assembly takes place in climate chambers with low humidity of about 0.1% (−60 °C dew point).

Fig. 3. Production steps for lithium-ion cells.

The fourth phase contains the start of operation of the cell. This means that the cell is charged for the first time (formation). During this process the solid-electrolyte-interface (SEI) is formed, which is highly responsible for the operation quality and the cycle stability of the cell. Afterwards, the cell is aged and tested in defined procedures. The further integration of cells in battery modules and systems, in particular the design of automated assembly systems, is addressed in [7,8].

During a research and development project, automated systems for the cell stacking, for the preconditioning of electrodes as well as for the detection of small particles on electrode surfaces have been developed and built up in a climate chamber at the *iwb*. These are illustrated in the following sections.

4. Process automation for cell stacking and preconditioning

Cells for automotive applications require economic production processes providing higher quality than for consumer applications. Adapted automated production techniques contribute highly in better qualities and lower product prices [9].

4.1. Cell stacking

As mentioned before, cell stacking is the central process in cell assembly, which was realized by z-folding with single electrodes at *iwb*. This process combines gentle material handling for the electrodes and fast process speed because of the processing of continuous separator material. The handling of single separator sheets is a serious problem particularly in dry conditions due to electrostatics. Fig. 4 shows the automated folding unit which has been developed in cooperation with the machine manufacturer Manz Tübingen GmbH. In this unit, the separator foil (A) is fed from the roll via tension and middle control to the guiding rolls (B). During the process the separator is fixed on the folding table (C) by blank holders and vacuum. While the table alternates (left-right), the separator is folded around the blank holders. With the handling systems (D) the electrode sheets (anode left, cathode right) are positioned on the stack. Two camera systems above the stacking

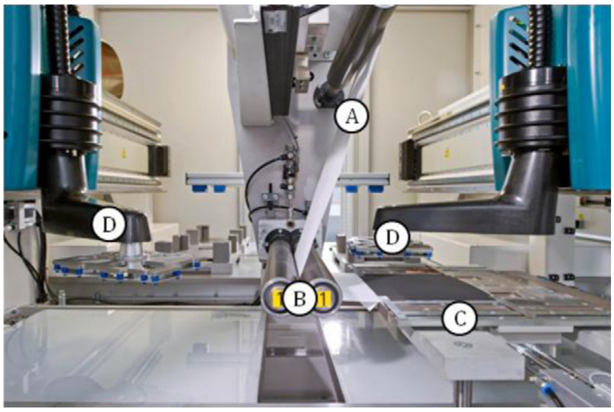

Fig. 4. z-Folding unit (TUM, Andreas Heddergott).