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Process and performance optimization by selective assembly of battery electrodes

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ABSTRACT

The increasing demand for electric vehicles and thus lithium-ion batteries results in a multitude of challenges in production technology. The reproducibility and performance of large scale batteries for automotive applications are very high. At the same time the production processes are complex and involve many uncertainties. Two essential process steps are the electrode coating and electrode package assembly. The mass loading of anodes and cathodes are determined by the coating process, where deviations can be caused by different reasons. The selective assembly of the electrodes is a reasonable way to balance the production variances. The contribution shows extended algorithms and their benefits and drawbacks of matching electrodes in order to improve the subsequent electrode packaging process. Here, the aim is to reach higher cell capacities and optimized performance values by "optimally" balanced electrodes regarding the mass loading ratio, which is also related to the specific material capacity.

1. Introduction

Lithium-ion batteries (LIBs) are currently the favoured technology for automotive applications, as their energy density is much higher than other electro-chemical energy storages, such as nickel–metal hydride batteries. Taking the historical background, e.g. of the consumer electronic into account, the LIB production technology know-how is located in Asian countries. In recent years, more and more production research emerges in Europe, as the battery system and especially the cells are the most valuable components in an electric vehicle. Hence, it is necessary to gain specified knowledge and experience about this widely interdisciplinary topic of material, design and production technology to advance the electromobility to meet further requirements of the automotive industry. This contribution focuses on the optimisation of the electrode packaging process, the last production step in the complex process chain, where the sensible electrodes are handled directly. During the process, the anode and cathode sheets are stacked, but electrically isolated by the separator. The selective assembly approach with regard to the mass loading ratio of the electrodes can lead to a homogeneous capacity distribution in the package and minimize lithium plating and anode oversizing effects. In the battery system assembly [1] similar assembly strategies on full cell level are pursued.

The next paragraphs first show the fundamentals of LIBs, their production steps and the description of the *z*-folding process. Then, the selective assembly strategy is explained in detail. For this purpose, the Hungarian method, or Kuhn–Munkres algorithm (K–M), for bipartite graph matching and its transfer to the electrode assembly is shown. In order to validate the approach, simulative and experimental results based on a normally distributed electrode sample are presented.

2. Battery production process

2.1. Structure of a lithium-ion battery

Lithium-ion batteries are based on the principle of the so-called intercalation compound in which Li^+ reversibly place and remove in a host lattice of the electrode. During the discharge process the solvated ions from the anode move through the electrolyte solution and the ionic conductive separator and intercalate in the cathode structure. This is usually associated with a volume expansion of the electrode. At the same time, the released electrons flow via the external circuit. The charging process takes place in reverse order (see Fig. 1).

Lithium-ion battery cells consist of alternately stacked anodes and cathodes, which are electrically isolated by ionic conductive separator. Electrodes consist of substrate materials, coated with a particular (active-)mass. In addition to the active materials, such as NMC for cathodes and graphite for anodes, binders and conductive additives are added. The substrate material for the anode is 10 μm thick copper and for the cathode is 20 μm thick aluminium, which are utilized as current collector. The separator is made of 20–30 μm polymer based functional, nanoporous film material. The total layer thickness (about 100–300 μm), the porosity and the particle size distribution are key parameters for the cell-design of

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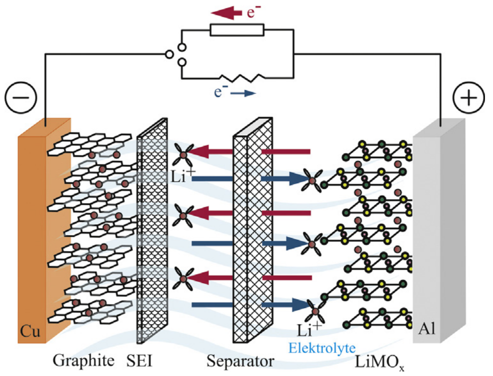

Fig. 1. Working principle and structure of a LIB.

high energy or high power applications. In addition to these the mass loading [mg/cm^2] is the value, which can be defined in the coating production step and determines the further function and performance of the battery cell. The essential interrelation of the anode and cathode is their capacity balancing to each other.

2.2. General production steps

The production of large scale LIBs is divided in the material preparation, electrode- and cell production and the post-processing step.

During the material preparation the electrode dispersion of active material, solvent (e.g. NMP), conductive carbon black and binder material (e.g. PVdF) is prepared in dry and wet mixing processes. Quality relevant aspects are the particle size, morphology, sphericity and rheology of the produces electrode slurry.

The mentioned foil Cu or Al substrate is coated with this electrode paste by slot die or doctor blade processes and dried afterwards. In order to enhance the energy density, adjust the particle size distribution and increase the interparticular contacting the electrode is calendered under high mechanical pressure. Depending on the battery cell design the parent material is confectioned via laser or blanking technology.

The electrode packaging process is the first step during the cell production. Here, the electrodes are stacked, folded or winded to a package or jelly roll in different shapes. Stacking or folding technologies are classical assembly tasks, as single electrode sheets have to be handled. Due to the sensibility of the surface coating and the flexibility of a single electrode, the gripper technology is crucial [2]. In general specified large area vacuum grippers are applied. The arrestors are afterwards contacted to the current collector by an ultrasonic or laser process. Then the electrode package is housed into a pouch foil, prismatic or cylindrical hard case. Afterwards the case is filled with electrolyte and partially sealed.

In the post-processing phase the battery is electrically activated by applying a minor current. During this formation step, the SEI (solid electrolyte interphase) is built-up. Gas can evaporate and has to be extracted. Finally the battery cell is sealed.

2.3. Electrode packaging process via z-folding

Production processes for manufacturing the electrode-separator package of a LIB are widely different. Winding, stacking or folding methods are commonly industrialized [3]. Generally, these technologies can be differentiated by the continuous and/or discrete material provision as shown in Fig. 2.

This contribution focuses on the *z*-folding process, which is established in the Battery LabFactory Braunschweig. Fig. 3 shows the machine configuration with the essential modules. The *z*-folding machine comprises an anode sheet ① and cathode sheet ② supply magazine, from which the electrodes are separated and transported via a handling unit ④ to camera-based rear inspection. Thereafter, the electrodes are transferred to a, 180° rotated, handling system where the front side inspection and the position

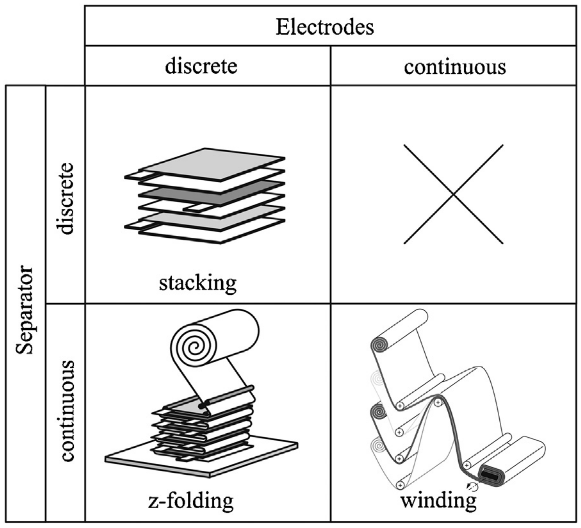

Fig. 2. Categorisation of the electrode packaging process.

detection and -correction takes place. If damage in the area of $d \geq 1$ mm on the electrode is determined the defective electrode can be sorted out. Flawless electrodes are positioned by a SCARA robot ⑤ on the stacking table ⑥. Until this process step, the anode and cathode space are physically separated from each other in order to minimize potential particulate cross-contamination. Parallel to this, the electrodes are suction cleaned from the front and the back. In addition, the process space is kept clean by a laminar flow box installed above the magazine area. The separator ③ is continuously supplied on the stacking table by a double dancer system ⑦. The web tension is controlled by a servo and a pneumatic dancer. In order to measure the mechanical tension on the sensible separator, a force sensor is used, which is integrated in

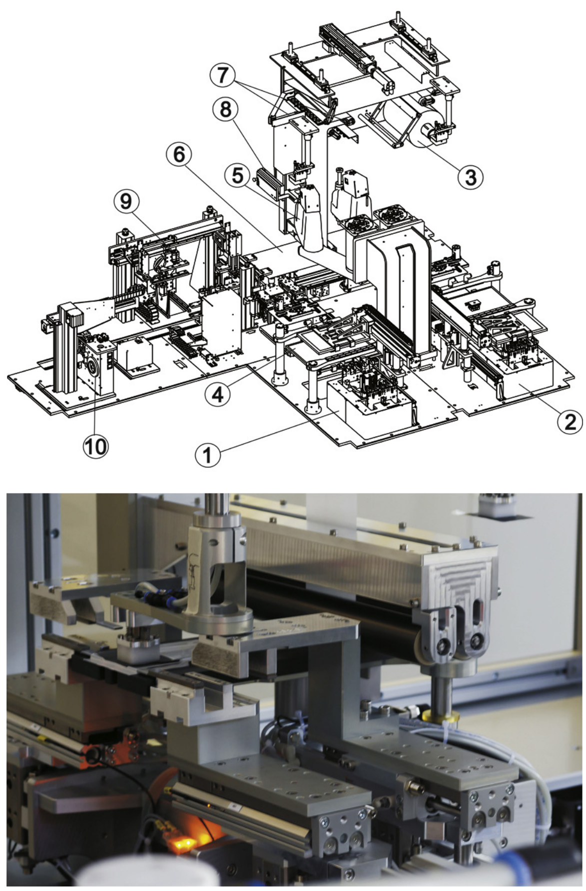

Fig. 3. Drawing of the *z*-folding machine (top), detailed view to the stacking table (bottom).