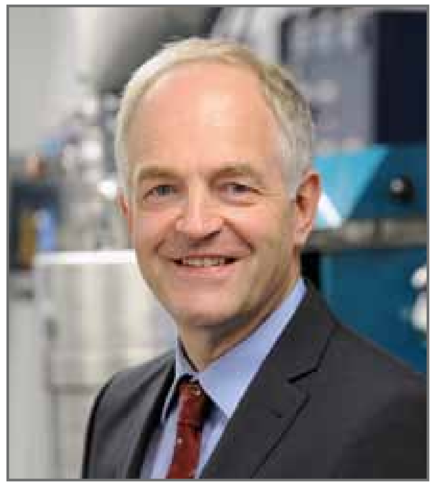
INTERNATIONAL BATTERY PRODUCTION CONFERENCE

2 to 4 November 2020

CONFERENCE BROCHURE

WELCOME



Dear participants of the IBPC,

While the pandemic greatly stifled the international economy in general, through the eyes of many in the battery industry it increased the transition speed towards the electrification of mobility and energy systems. Batteries are still at the core of the electrification and a key driver of the global mobility revolution. The last years have shown an enormous growth in demand, production capacity and technological progress in terms of energy capacity, fast charging ability and costs reduction. However, the end is still not in sight, as we are experiencing a fast innovation rate regarding new materials, cell and pack designs that need to be transferred from the lab scale to the industrial mass production.

When we started preparing the conference at the end of last year, we could not have imagined how the world could change in such a short time period. Thrilled with the success of the IBPC 2019 with over 240 participants and 56 exciting presentation on recent advancements in battery production, we went on to plan the 2020 conference, discussing even potential participant limits in order to maintain the familiar atmosphere of the conference. Then the Covid-19 pandemic took over the world. The high risk of infection deeply changed human interaction, resulting in many cancelled conferences and gatherings this year. We believe that the technological advancement in battery engineering thrives on the interdisciplinary exchange between different engineering domains as well as academic research and industry.

We are happy to support this exchange by presenting and hosting the IBPC 2020. In reaction to the increasing infections all over Europe, Germany and Braunschweig, this year's IBPC will be a fully online event. The program was adapted to support the online event, while still enabling sharing and discussing recent technological achievements and research results. This year's plenary talks, presentations and poster sessions address the electrode, cell, module and pack production, cell and pack design, safety, simulation, sustainability and the digitalization of the battery production. In addition to liquid phase batteries, the conference addresses the production of all-solid-state and solid polymer batteries. We are very happy welcome speakers along the battery value chain and are excited for their contribution towards the battery production community. We are particularly thankful for the support of our partners VDMA Battery Production, the German competence cluster on battery Production ProZell and welcome all their members. A special thank goes to our sponsors Custom Cells, Bio-Logic, Tec5, Coperion, Netzsch and C3 Prozess- und Analysentechnik. Their support enables us to maintain the high quality of the conference under these difficult circumstances.

We wish you all a very warm welcome, interesting talks and exciting discussions.

Prof. Christoph Herrmann & Prof. Arno Kwade

Ch. Herrmann A. Kwade

BATTERY LABFACTORY

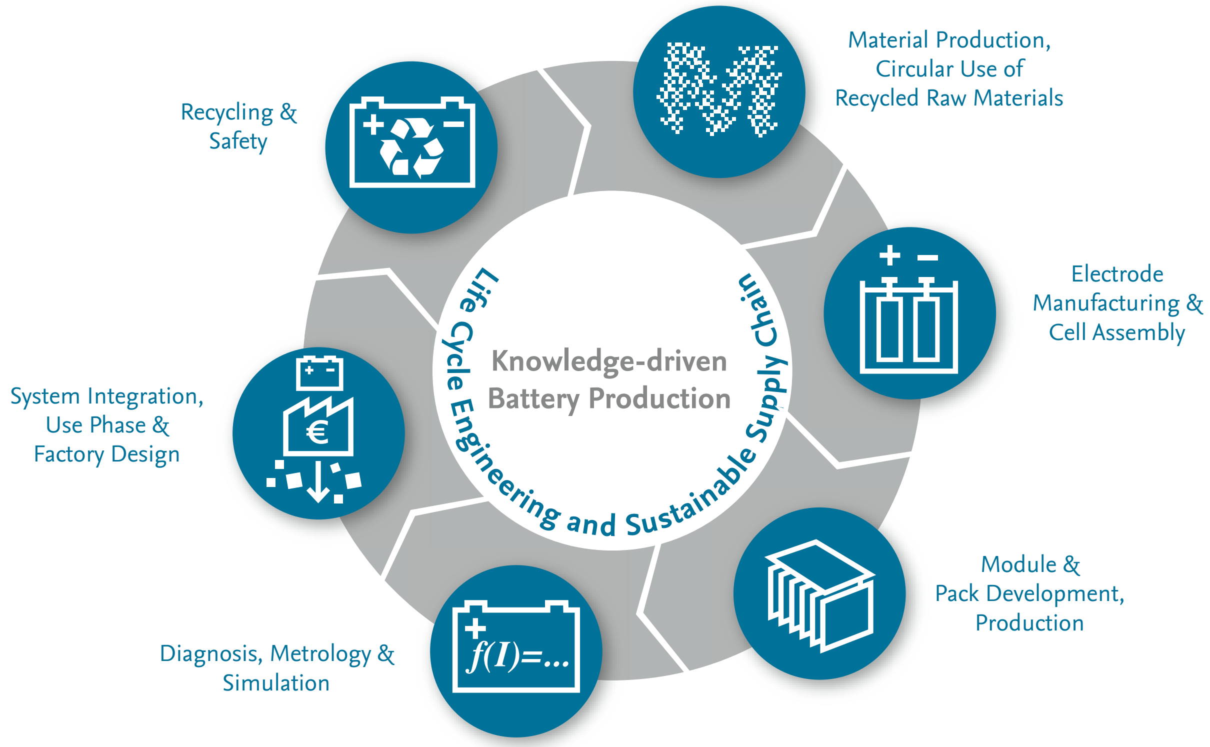
The Battery LabFactory (BLB) stands for an open research infrastructure to investigate and develop electro-chemical storage devices from laboratory to pilot plant scale. The research spectrum covers the entire va-lue cycle, from material, electrode and cell manufacturing, up to recycling as well as the subsequent active material resynthesis from recycled raw materials.

The BLB holds the production infrastructure and characterizing equipment to develop large-sized batteries as well as battery modules and packs. This allows the research on fundamental and application-oriented aspects. The scope of BLB is to establish a knowledge-driven electrode and cell production to accomplish a fast transfer of R&D-based developments into technical or pilot scale production processes. For this purpose, the transdisciplinary team of BLB engineers and scientists combine their expertise. In detail, 9 institutes of the TU Braunschweig, one from TU Clausthal and one from LU Hannover combine their knowledge and scientific competence. Furthermore, the Fraunhofer Institute for Surface Engineering and Thin Films IST and the Physikalisch-Technische Bundesanstalt Braunschweig (PTB) complete the joined Battery Lab-Factory Braunschweig.

The Battery LabFactory represents an open platform for R&D on processes, cell design, diagnostic and sim-ulation of todays and future battery technologies.

BATTERY LABFACTORY BRAUNSCHWEIG

CIRCULAR BATTERY PRODUCTION



CONTENT

PARTNER

The NETZSCH Business Unit Grinding & Dispersing offers an extensive machine program for process engineering, providing solutions for wet and dry grinding, mixing, dispersing and deaeration. Long-term experience, consistent development work, daily contact with our customers and developments with more than 100 patents ensure our technical competence and further attest to our quality-consciousness. The bundling of process-engineering expertise and the extensive machine program, ranging from laboratory to production machines to complete production lines, is unique worldwide.

www.netzsch-grinding.com

CUSTOMCELLS® is one of the leading companies in the development of special lithium-ion battery cells. At the company sites in Itzehoe (Schleswig-Holstein-Germany) and Tübingen (Baden-Württemberg- Germany) CUSTOMCELLS®- Made in Germany- develops and produces application-specific battery cells from prototypes to small and medium series. On the basis of flexible manufacturing concepts and state-of-the-art research and production facilities, CUSTOMCELLS® guarantees high-tech solutions for special applications and tailor-made development and production of electrodes, electrolytes, battery cells and battery modules, depending on the customer's requirements profile. CUSTOMCELLS®'s extensive process engineering know-how and deep understanding of electrochemistry guarantee short periods of time for the realization of individual cell characteristics.

www.customcells.org

BioLogic Science Instruments SAS, with its corporate office in Seyssinet-Pariset, is a French designer and manufacturer who offers powerful laboratory research instruments and software since 1983. The company is characterized by its close relationships with battery development and testing laboratories around the world. With our high precision, high-performance product range of potentiostats, galvanostats, battery cyclers and impedance analyzers we are able to cover a wide field of research: New battery technology, fuel cells, photovoltaics, corrosion, super capacitors, and bio-sensors to name a few. The modularity of our multi-channel potentiostats and our wide range of battery characterization accessories offers highest flexibility to configure the appropriate device according to your needs.

www.bio-logic.net

Coperion is the international market and technology leader in compounding systems, feeding technology, bulk materials handling systems and services. Coperion designs, develops, manufactures and maintains systems, machines and components for the plastics, chemicals, pharmaceuticals, food and minerals industries. Coperion has 2,500 employees, nearly 30 sales and service companies worldwide and a total of 30 extrusion systems permanently available for testings.

Your Partner in Extrusion of Battery Materials: Coperion is your partner for the continuous production of anode and cathode slurries, battery separator films and solid-state battery compounds. The combination of high-class Coperion ZSK twin screw extruders with high-accuracy Coperion K-Tron feeders and reliable rotary valves ensures continuous processes with high reliability, long operating times and constant high product quality.

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tec5 has been developing and manufacturing high-quality systems and components for process analytics since 1993. Our industrial-grade spectrometers are used in process monitoring and control to optimize products and, of course, the processes themselves in a wide spectrum of applications. Designed variants are available for inline or online operation in stationary systems or for mobile use.

The metrological functionalities of our systems and components are based on established analytical methods like UV/VIS, NIR or Raman spectroscopy. Moreover, we provide process-enabled LIBS systems for elemental analysis.

All our variants are available as microcontroller-based systems with full low-level implemented chemometric data analysis and processing routines. These enable modern, real-time capable smart sensing devices with no need for PC-based software.

www.tec5.com

C3 is the distribution partner for different manufacturers of analytical instrumentation and lab equipment in the DACH region. We take care of application consulting, sales, training and service/supportf for our customers. For the application field „battery“ we offer different equipment.

Electrochemical systems and accessories from Gamry Instruments and ALS are available for the characterisation of batteries and battery components for R&D and QC. The product range covers full-featured potentiostats capable of performing all techniques, including electrochemical impedance spectroscopy as well as a high-performance systems for challenging tasks and basic research. Booster for high current applications and multichannel potentiostat systems complete the portfolio.

The high efficient planetary centrifugal mixers from THINKY are used to homogenize and degas electrode slurries.

www.c3-analysentechnik.de

PARTNER

VDMA

Batterieproduktion

The VDMA Battery Production department is the partner for all questions relating to machine and plant construction in the field of battery production. The member companies of the department supply machines, plants, machine components, tools and services for the entire process chain of battery production: From raw material preparation, electrode production and cell assembly to module and packaging production. The current focus of VDMA battery production is on Li-ion technology. We research technology and market information, organize customer events and road shows, hold our own events, such as the annual conference, which has established itself as an important industry meeting place, and are in dialogue with research and science on current topics and on joint industrial research.

http://battprod.vdma.org

ProZell
Kompetenzcluster
zur Batteriezellproduktion

The aim of the competence cluster is to research and improve the entire process chain of the battery cell production and assess the influence of each individual production step on cell properties, product development costs and sustainability. In cooperation with the BMBF, the KLiB and the ProZell management board, the active ProZell network successfully creates synergies between science and industry. Together, they lay the foundation for a high-performance and cost-effective battery cell "Made in Germany".

www.prozell-cluster.de

Scientific Partner
Fraunhofer
IST

The Fraunhofer Institute for Surface Engineering and Thin Films IST in Braunschweig is an innovative partner for research and development in surface technology, with expertise in the associated product and production systems. Together with customers from industry and research we develop customized and sustainable solutions: from prototypes, through economic production scenarios, to upscaling to industrial magnitudes- and all this whilst maintaining closed material and substance cycles. Coating and surface technology is the key to innovative products and systems: Through modification, patterning and coating of the surface, a wide range of functions and functionalities can be realized. On the basis of a broad spectrum of processes and coating materials we create the optimum process chain for the respective task.

www.ist.fraunhofer.de

PROGRAM

CONFERENCE DAY 1 | Nov. 2nd

8:30 I Alfaview Check-In

9:00 I Welcome by the Conference Chairs

9:15 I Keynote by Wolfgang Bernhart, Roland Berger
Lithium-Ion Battery Markets and Value Chain – Changing Business Models

9:50 I Keynote by Jacques Eksteen, Future Battery Industries CRC
Sustainable Material Sourcing

10:25 I Electrode Production (I)
Chairs: Prof. A. Kwade, Dr.-Ing. W. Haselrieder

Customizing Lithium Ion Cells- from first material to series production
Anne Baasner, Custom Cells Itzehoe

Simulation based prediction of carbon black particle sizes in high intensity dispersion processes
Julian Mayer, TU Braunschweig | Institute for Particle Technolgy (iPAT)

Optimized High-Energy NCM622 Electrodes for Lithium-Ion Batteries Fabricated by Extrusion-Based Slot-Die Coating
Sebastian Reuber, Fraunhofer Institute for Ceramic Technologies and Systems IKTS

aNIR-Technology a game changer in electrode production?
Kai K. O. Bär, adphos Digital Printing GmbH

11:13 I Discussion

11:25 I Break

11:45 I Electrode Production (II)
Chairs: Prof. A. Kwade, Dr.-Ing. W. Haselrieder

Energy Efficient LIB Production
Silje Nornes Bryntesen, Norwegian University of Science and Technology (NTNU)

Advances in water-based electrode processing for high energy Li-ion battery manufacturing: Si-Gr/NMC622 cells
Iker Boyano, CIDETEC

Effect of graphite anode morphology on the onset of lithium-plating in lithium-ion batteries
Alexander Adam, BMW Group

12:21 I Discussion

12:33 I Industry Session
Inline quality control for continuous electrode slurry production
Adrian Spillmann, Bühler AG

Preparation and functionalization of active materials with intensive mixers to increase the performance of electrodes
Stefan Gerl, Maschinenfabrik Gustav Eirich

Continous extrusion of electrodes
Nicole Neub, Coperion GmbH

System HELIOS for closed, continuous industrial processing of battery slurries in gigafactories
Dimitrios Makrakis, NETZSCH

Process Analytical Technology for Industrial Battery Production
Christian Lux, tec5

13:07 I Lunch Break

13:52 I Keynote by Peter Schroth, BMBF
From New Concepts to Applications: The Battery Funding Strategy of the German Federal Ministry of Education and Research

14:27 I Postersession online

15:12 I Cell Assembly (I)
Chair: Prof. K. Dröder

Building the pan-European battery ecosystem
Stefan Wolf, VDI/VDE Innovation + Technik GmbH

Sustainable and automated Li-ion cell production
Ulrike Polnick, Industrie-Partner IP PowerSystems GmbH

Powering tomorrow with energy-efficient dehumidification systems and dry rooms
André Meyer, Munters GmbH

15:48 I Discussion

16:00 I Break

16:20 I Cell Assembly (II)
Chair: Prof. K. Dröder

Evaluation of flexible cell assembly processes and novel, flexible production equipment
Tobias Storz, Karlsruhe Institute of Technology (KIT) | wbk Institute of Production Science

Design parameters for a continouos stacking process in cell assembly of lithium-ion batteries
Christina Boeselager, TU Braunschweig | Institute of Machine Tools and Production Technology (IWF)

Filling and Formation of large Li-ion-cells – where scaling up is non-linear
Stefan Roessler, Zentrum für Sonnenenergie und Wasserstoffforschung Baden-Württemberg (ZSW)

16:56 I Discussion

17:08 I Battery Production 4.0
Chair: Prof. C. Herrmann

Industry 4.0 Software Architecture for Battery Cell Manufacturing
Bob Zollo, Keysight Technologies

Analyzing and tailoring quality control measures for managing product variance in battery cell production lines.
Anna Sophia Kollenda, Technical University Munich | Institute for Machine Tools and Industrial Management (iwb)

On-Line Solutions to Optimize Electrode Coating Uniformity in Battery Production Processes
Gareth Joseph, NDC Technologies

Towards smart battery cell manufacturing: from in-line quality control to cyber-physical systems in electrode production
Marcel Dittmer, TU Braunschweig | Institute for Particle Technolgy (iPAT)

17:56 I Discussion

18:08 I End of Day One

19:30 I Virtual Meet & Greet

PROGRAM

CONFERENCE DAY 2 | Nov. 3rd

8:30 I Keynote by Fredrik Hedlund, Northvolt
Northvolt – scaling up green cell manufacturing in Europe

9:05 I Keynote by Christian Hagelüken, Umicore
Battery materials in a circular economy – opportunities, challenges and requirements

9:40 I Industry Session

Design considers, safety lessons and new developments of lithium-ion batteries for industrial applications
Dr. John De Roche, Aentron GmbH

Mono cell inspection in the battery cell production- How to increase and ensure the position accuracy of the electrodes in-line in the lamination and stacking production process?
Klaus Hamacher, BST eltromat International GmbH

Electrochemical Impedance Spectroscopy (EIS) for battery cells, module and packs
Albert Gröbmeyer, Keysight Technologies

BioLogic- Shaping the future. Together.
Sandra Möller, Bio-Logic

Products for EIS Measurements on Battery Cells
Dirk Bublitz, C3 Gamry

10:14 I Break

10:34 I Module & Pack Production
Chair: Prof. K. Dilger

Matrix Production Lines – Production Power for the World of Tomorrow
Alexander Weis, SCIO Technology GmbH

Production of Future-Proof Automotive Battery Systems
Thomas Decker, Webasto SE, Energy & Components, Battery Systems

Leak testing of battery packs during pack production
Thomas Odenthal, INFICON GmbH

Laser Meets Battery Cells
Sören Hollatz, Fraunhofer Institute for Laser Technology ILT

11:22 I Discussion

11:34 I Break

11:54 I Keynote by Jürgen Janek, Justus Liebig University Giessen
From Solid Electrolytes to Solid State Batteries – Key Challenges

12:29 I Production of Solid State Batteries
Chairs: Prof. A. Kwade, Dr.-Ing. W. Haselrieder

Processing of All Solid State Batteries: Recent Advances
Ingo Bardenhagen, Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM

Structural and electrochemical characterization of polymer-based all-solid-state cathodes manufactured by a scalable process chain
Laura Helmers, TU Braunschweig | Institute for Particle Technolgy (iPAT)

Influence of the dispersing method on the performance of Lithium Solid-State batteries
Maica Morant-Miñana, CIC energiGUNE

Processing of Sulfide Solid Electrolytes for All Solid State Battery electrodes
Henry Auer, Fraunhofer Institute for Ceramic Technologies and Systems IKTS

The potential of thin film technologies in the production of ASSB
Nikolas Dilger, Fraunhofer Institute for Surface Engineering and Thin Films IST

13:29 I Discussion

13:41 I Lunch Break

14:26 I Postersession online

15:11 I Electrode, Cell and Module Diagnostic during Production
Chair: M. Kurrat

An analytical method for the quantification of magnetic particle contaminants in powder materials for lithium-ion batteries
Giulio Ferraresi, Imerys Graphite & Carbon

Evaluation of an In-Line particle characterization method for Battery-Materials and-slurries
Sebastian Maaß, SOPAT GmbH

Classification and risk assessment of lithium-ion battery cells by parameter-based methods
Louisa Hoffmann | Stefan Doose, TU Braunschweig | Institute for High Voltage Technology and Electrical Power Systems (elenia), Institute for Particle Technolgy (iPAT)

15:47 I Discussion

15:59 I Cell Finishing
Chair: Prof. M. Kurrat

Formation- a critical production step for cell quality?
Philip Niehoff, University of Münster | MEET Battery Research Center

Prospects of using predictive quality during cell finishing to reduce the process time
Sandro Stock, Technical University of Munich (TUM) | Institute for Machine Tools and Industrial (iwb)

16:23 I Discussion

16:35 I Break

16:55 I Sustainability
Chair: Prof. C. Herrmann

CO2 optimized battery manufacturing in Europe with upstream integration potentials
Paul Wolff, P3 automotive GmbH

LCA of different battery cell technologies taking uncertainty corridors into account
Philipp Engels, TU Braunschweig | Institute of Machine Tools and Production Technology (IWF)

Towards sustainable supply chains for batteries: Insights from a spatially differentiated assessment of environmental and social impacts
Christian Thies, TU Braunschweig | Institute of Automotive Management and Industrial Production (AIP)

17:31 I Discussion

17:43 I End of Conference

POSTER SESSION

Electrode Production

P1-01 Novel Binder Approach for Processing Aqueous Li[Ni0.6Mn0.2Co0.2]O2 Electrodes in Lithium-ion Batteries
André Müller

P1-02 Solvent-free production of Li[Ni0.6Mn0.2Co0.2]O2 electrodes for lithium-ion batteries through powder calendering
Andreas Gyulai

P1-03 Identifying the influence of the particle size and morphology of electrode materials on the process of calendering
Ann-Kathrin Wurba

P1-04 Together with partners CUSTOMCELLS® is developing a series production of high-quality lithium-ion battery cells in the public funded project KomVar
Anne Baasner

P1-05 Scalability of the mixing process: from batch to continuous processing
Desiree Grießl

P1-06 A simulation approach to investigate the effect of electrode waviness after calendering on the stacking accuracy of pouch cells
Dominik Mayer

P1-07 Development of a single-step anode production process integrating coating, drying and calendaring
Eike Wiegmann

P1-08 Vacuum post-drying kinetics of Li-ion battery electrodes with different structural properties and coil geometries
Fabienne Huttner

P1-09 Alternative binder and intrinsic conductive polymers in cathode production for LIB cells
Helene Jeske

P1-10 Preparation of silicon-carbon composites by fluidized bed granulation
Jannes Müller

P1-11 Optimization of electrodes based on Si@C for the next generation of LIBs
Jonathan Flórez Montaño

P1-12 Post Lithium Storage- Processing of Sodium Ion Battery Electrodes
Julian Klemens

P1-13 Investigation and evaluation of high-energy hybrid anodes containing different types of Hard Carbon
Laura Gottschalk

P1-14 Influence of film thickness and calendaring process on the coating properties and electrochemistry of cathodes for Sodium-Ion Batteries
Luca Schneider

P1-15 Influence of intensive dry mixing of graphite based anode powders on slurry, electrode and electrochemical properties in lithium-ion batteries
Marcel Dittmer

P1-16 A reliable large-scale implementation of water-based slurry technology for production of high-performance lithium-ion batterie
Petronela Gotcu, Hilmi Buqa

P1-17 Influence of binder on the structure and performance of anodes
René Jagau

P1-18 Edge formation during the coating process of li-ion battery electrodes
Sandro Spiegel

P1-19 Simulation of water mass transport during the post-drying process in the production of lithium-ion batteries
Thilo Heckmann

P1-20 The importance of passive materials in thick Li-ion battery electrodes
Tobias Knorr

P1-21 Inline quality control for continuous electrode slurry production
Adrian Spillmann

P1-22 FlexCaD- Flexible Coater and Dryer for Battery Electrodes
Andreas Altvater

P1-23 DEVELOPMENT AND OPTIMIZATION OF NEW DRYING CONCEPTS FOR FORMAT AND MATERIAL FLEXIBLE BATTERY ELECTRODES
Jonas Mohacsi

P1-24 Preparation and functionalization of active materials with intensive mixers to increase the performance of electrodes
Stefan Gerl

Cell Assembly

P2-01 Continuous processes for the high-throughput cell assembly of Li-Ion batteries
Christina von Boeselager

P2-02 Welding of electrode-separator assemblies using blue laser radiation for the high-speed production of Li-ion battery cells
Johanna Helm

P2-03 Influence of the porosity ratio on the performance of Li-ion cell by using PVdF-based separator
María Porcel-Valenzuela

P2-04 Investigation of the influence of different electrolyte solvents and the ambient medium on the wetting properties of cell components
Nicolaj Kaden

P2-05 Method for the Production of Reproducible Lithium-Ion Coin Cells
Paul-Martin Luc

Battery Production 4.0

P3-01 Identification and selection of variables in battery cell production for analyses of process improvement using the example of dry coating with the help of Failure Mode and Effects Analysis (FMEA)
Andreas Aichele

P3-02 Evaluation of production processes and quality assessment of Li-Ion batteries using microscopy and machine learning
Andreas Kopp

P3-03 Process Analytical Technology for Industrial Battery Production
Christian Lux, Martin Hühn

P3-04 Global Warming Potential of a new recycling method for Li-Ion Batteries
Mojtaba Faryadras

P3-05 Analysing interdependencies between processing parameters , product quality and production costs – Exemplified by the production of Lithium metal anodes
Nikolas Dilger

Module & Pack Design & Safety

P4-01 Characterisation and Comprehensive Analysis of Protective Safety Devices in Pouch Cells on Cell Level
Houssin Wehbe, Filip Vysoudil

P4-02 Electro-thermal optimization of safe fast charging strategies
Robin Drees

POSTER SESSION

Production of Solid State Batteries

P5-01 Scalable tape-casting of Lithium thiophosphate (β-Li_3PS_4) solid electrolyte and composite cathodes for all-solid-state batteries
Adel Elsayed

P5-02 Effect of Microstructure on Ionic Conductivity of Polymer All-Solid-State Electrodes
Christine Burmeister

P5-03 Influencing the conductive pathways within polymer and hybrid electrolyte cathodes
Jessica Gerstenberg

P5-04 Laser cutting process of lithium metal foil for all-solid-state battery systems
Lars Oliver Schmidt

P5-05 Upscaling of mechanochemical syntheses of sulfide-based solid electrolytes
Michael Grube

P5-06 The FestBatt-Cluster of Competence on Solid-State Batteries
Simon Burkhardt

Electrode, Cell and Module Diagnostics during Production

P6-01 Large Amplitude Oscillatory Shear Rheology of Electrode Slurries
Carl Reynolds

P6-02 Daniel Neb
Standardization of Testing Methods for the approval of electric vehicle power batteries for Chinese and European markets

P6-03 Continuous non-destructive quality monitoring of a battery suspension or dispersion by inductive electrical impedance and ultrasonic spectroscopy
Marcel Wild

P6-04 Electrochemical Impedance Spectroscopy (EIS) for battery cells, modules and packs
Albert Gröbmeyer

Recycling & Sustainability

P7-01 Life cycle sustainability assessment of potential battery systems for short-range electric aircraft
Alexander Barke

P7-02 Environmental Screening of Environmental Impacts of ASSB
Almut Kiesewetter

P7-03 Characterization of Li-Ion battery modules for second-life applications
Daniel Kehl

P7-04 A view on battery production from the perspective of second life projects
Felipe Salinas

P7-05 Environmental and socio-economic sustainability assessment of an all-solid-state battery system
Jan Linus Popien

P7-06 Life cycle assessment of metal and liquid-free organic lithium-ion batteries as sustainable and safe energy storage technologies
Merve Erakca

P7-07 Application of functional biopolymers for sustainable batteries
Raymond Leopold Heydorn

POSTER ABSTRACTS

Electrode Production

Novel Binder Approach for Processing Aqueous Li[Ni0.6Mn0.2Co0.2]O2 Electrodes in Lithium-ion Batteries

André Müller
Karlsruhe Institute of Technology (KIT) | Institute for Applied Materials – Energy Storage Systems (IAM-ESS)

The aqueous processing of lithium-ion battery (LIB) cathodes enables the removal of the teratogenic solvent N-Methyl-2-pyrrolidone (NMP) towards a sustainable and environmentally benign production. Even though the aqueous manufacturing process is already applied to graphite anodes, it cannot simply be transferred to modern LIB cathodes, as the performance degradation based on transition metal oxides processed in aqueous environments is still an ongoing concern.

This project focuses on a novel approach for the application of water compatible binder system. Until now, the electrochemically, chemically and thermally stable polyvinylidene fluoride (PVDF) solved in NMP is established as the standard binder for cathodes. However, first attempts have already been made to replace PVDF with an aqueous mixture of sodium carboxymethyl cellulose (Na-CMC) with styrene butadiene rubber (SBR). Since PVDF also exists as a water-based latex suspension, it can be used as a substitute for the less stable SBR in aqueous environments. To investigate this alternative binder system, a standardised electrode manufacturing process was used, which compares different electrode mixtures, e.g. state-of-the-art NMP-based NMC cathodes, or NMC cathodes with a mixture of CMC/SBR binder, with the new approach. The rheological properties of the slurries were analysed before the coating process, whereas the coating morphology was characterized after the drying and calendaring process. Finally, electrochemical characterization methods such as galvanostatic cycling (CCCV), etc. of pouch cells were conducted.

While the rheological properties show suitable processing characteristics, the cohesion and adhesion of the coating on the current collector still show problems. This can be attributed mostly to the corrosion of the aluminium foil by an increase of the pH-value of the slurry. It is caused by dissolved lithium ions in water, which then react to basic lithium hydroxide LiOH. Since the pH rise with PVDF latex is more drastic than in slurries containing SBR, additional measures have to be added to mitigate the corrosive impact.

Solvent-free production of Li[Ni0.6Mn0.2Co0.2]O2 electrodes for lithium-ion batteries through powder calendering

Andreas Gyulai
Karlsruhe Institue of Technology (KIT) | Institue for Applied Materials - Energy Storage Systems (IAM-ESS)

The omitment of organic or aqueous solvents in the processing of lithium ion battery (LIB) cathodes offers the possibility to highly reduce processing costs and the negative environmental impact of cathode manufacturing. The present work addresses this approach by investigating the direct calendering of a dry powder mixture consisting of state of the art cathode materials.

Challenges are found in the processibility of the powder mixture. Poor flowability expressed through high shear forces in the powder feed leads to thick electrode layers with high local inhomogenities. Additionally, layer stability and strong adhesion to the calender rolls have to be addressed.

The approach of this work is to increase powder flowability by narrowing down the particle size distribution of the powder mixture. Homogenous distribution and coating of the conductive additive onto the active material by high intensity mixing can greatly decrease shear forces in the powder mixture. The addition of non-solvent plasticisers can further increase powder flowability. Furthermore, high processing temperatures and the use of PVDF and PTFE binders with different physicochemical properties offer the possibility to increase the flowability of the feed while also adjusting layer stability and adhesiveness. Rheology analysis of the powder modifications show the extent of potential increase in processibility. Resulting cathode properties, such as thickness, porosity, capacity, conductivity and cycling stability are analysed in regards of the process parameters and feed material rheology.

Identifying the influence of the particle size and morphology of electrode materials on the process of calendering

Ann-Kathrin Wurba
Karlsruhe Institute of Technology (KIT)

Current developments in the electric mobility sector and the need for the storage of energy from renewable sources lead to a growing demand for lithium-ion batteries (LIB). Although they provide high energy densities, the increasing requirements push this technology to its performance limits. Furthermore some of the commonly used electrode raw materials face alarming political, ecological and economic risks. The DFG-funded project POLiS Cluster of Excellence therefore aims to develop sustainable battery materials to produce safer batteries with higher performance properties.

In addition to the choice of the material each process step has an impact on future cell performance. High energy densities are obtained by a properly adjusted calendering process. The compression of the electrode material leads among other improvements to an increase of the volumetric energy density. Hence, it is of great importance to understand the process of calendering to achieve satisfying electrochemical cell properties.

This work investigates the influence of material characteristics on the calendering process. One promising post-lithium candidate is sodium with its corresponding anode material hard carbon. This study focusses on analysing the correlation between the particle size and morphology of hard carbon and the generated anode properties after calendering. Furthermore the slurry composition and drying conditions are taken into account. Line load, web tension and temperature are varied calendering process parameters. Resulting compaction rates and adhesive forces are presented and scanning electron microscopy images complete the analysis of the material behavior. A stereo camera system quantifies the distortions caused by calendering. Finally conductivity measurements rate the quality of the calendered anode material.

These results contribute to building a tool for the prediction of the processability of future battery materials.

Together with partners CUSTOMCELLS® is developing a series production of high-quality lithium-ion battery cells in the public funded project KomVar

Anne Baasner
Custom Cells Itzehoe

Lithium-ion batteries are considered a key technology for many areas of industry. Many energy-autonomous products are already differentiated by the quality of the energy storage device, with the predominant gain in performance being due to the lithium-ion cells used. In addition to the large consumer product markets and the increasingly important automotive applications, more and more niche markets are also coming to the fore. All markets have in common that the increasing differentiation of products, which takes place via the energy storage, greatly increases the pressure on previously established development and adaptation cycles to convert development results into products more quickly. So far, cell development, like cell production, has mainly taken place in Asia. This initial situation poses considerable challenges for technology users. There are already supply gaps on the cell market, which mainly affect small and medium-sized companies that have to supply themselves with cells. In addition, there is no realistic option for companies to have cells developed and produced according to their specifications and performance profiles, since the purchase quantities in niche markets are lower and accordingly less attractive for the few large Asian cell manufacturers.

In order to solve this situation, besides large-scale production of cells in Germany and the EU, companies are also required that can offer competitive, variable cell production for the production of small series and for the production of development series. The KOMVAR project deals with the development and demonstration of such a variant production over a period of two years. The project includes the development and construction of a demonstrator cell production facility. The systems should be able to produce various cell designs and cell technologies in high quality in small and medium quantities. In cell production runs, up to four different cell types are manufactured in small series and checked for quality during the project period. Data on throughput, changeover times and consumption are recorded in these test runs. These data flow into a higher-level economic concept, which, as a result of the project, is intended to confirm the general feasibility of the concept by means of a targeted cell price determined in advance.

The project represents an important cornerstone for the catch-up of the German and European industry in the field of lithium-ion cell development and production by building up additional capacities, knowledge and jobs in this area and paving the way for new cell developments, which can then lead to cell production capacities. More information: https://www.customcells.org

Scalability of the mixing process: from batch to continuous processing

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BMW AG

The mixing process is an essential step in the electrode production. Apart from material selection and constitution, remarkable influence of the mixing procedure on the electrode properties have been detected. Through the energy application of a mixing device, materials are supposed to be homogenized and potentially desagglomerated. Different approaches exist in order to produce an electrode slurry.

State of the art for the mixing process still prevails in slurry production, whereas continuous mixing offers several advantages concerning quality and costs.

In this work, an approach based on an empirical model in order to describe the mixing processes has been developed. Furthermore, process knowledge from the state of the art batch mixing can be transferred to the continuous process.

The results show the influence of production parameters on the properties of the intermediate product and the resulting battery cell. A detailed comparison of both process variants is concluded.

A simulation approach to investigate the effect of electrode waviness after calendering on the stacking accuracy of pouch cells

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In order to develop more powerful lithium-ion batteries, there are currently great efforts to increase the volumetric and gravimetric energy density of battery cells. For this purpose, the compositions of existing material systems are optimised as well as new material systems are developed. Furthermore, production parameters are optimized in order to achieve the highest possible quality of the cells with the present material system. However, interactions between material and production systems are often unknown or must be investigated in time-consuming experiments. Additionally, interactions between individual process steps are often unknown.

Simulation models can support mapping the respective interactions in order to predict effects of modifications of material properties or machine parameters on the required quality. Focusing on three process steps of pouch cell production, calendering- separation- stacking, calendering has a particular influence on the achievable stacking accuracy. Therefore, a new simulation approach is presented in this research which relates the waviness of the electrode after calendering to the stacking accuracy achieved in the production of pouch cell stacks.

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Development of a single-step anode production process integrating coating, drying and calendaring

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Conventional electrode coating processes for Lithium-ion batteries, such as doctor blade or slot die coating, require relatively low solids contents, which entail long drying times and the associated high energy and investment costs [1]. In this form of electrode processing, due to the high solvent content, segregation of inactive components of the electrodes, which impair their physical properties, can be detected [2],[3]. Therefore, a new process based on very low solvent content, with the ability to integrate the electrode manufacturing steps coating, drying and calendaring into one process-step, was developed.

The process was investigated for the manufacturing of high viscous water based anodes and N-Methyl-2-pyrrolidone based cathodes. With a mass content of less than 25% of water in the anode slurry, the solid ingredients were processed together with the solvent in a twin screw extruder combined with a strand pelletizer. Such a processing enables a highly filled paste to be produced, which is stable in storage. Afterwards, the obtained high viscous electrode granulates were coated directly within the calender on the electrode copper foil. Directly after the calendering rolls, the coating is dried continuously using an IR radiator field. In addition, this type of coating achieves an increased initial density of the electrode so that calendering is not unconditionally necessary.

The development of this new and innovative electrode manufacturing process for different anode compositions will be shown. The anodes are based on graphite respectively graphite silicon composites as active material and additionally inactive materials like carbon black and binders. Due to the high viscosity of the electrode pastes, the individual components such as the binder and active material are exposed to high shear stresses during the processing inside the extruder and calender gap, respectively. This requires mechanical and thermal stability of the used binders. Therefore, different types of binder materials and different amounts of the binders were tested. In addition, formulation studies were carried out in the twin-screw extruder to achieve a better distribution of inactive materials in the electrode pastes in order to improve the intrinsic properties of the electrodes. Based on the formulation and process parameter studies the mechanic properties like the adhesion strength and the cell performance of the new processed electrodes will be shown compared to conventional manufactured electrodes. The results show, that the produced anodes show a higher cell capacity at higher C-rates due to the structural changes of the active material based on the high shear stress within the twin screw extruder. In addition, the highly viscous processed pastes show a storage stability over several weeks, whereby a temporal decoupling of production and coating can be guaranteed.

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Vacuum post-drying kinetics of Li-ion battery electrodes with different structural properties and coil geometries

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The manufacturing of Lithium ion batteries (LIBs) includes a lot of complex process steps and is subjected to various influences. A quite critical contamination is re¬presen¬ted by moisture [1], which can cause cell degradation and thus poses a high safety risk. For this reason, the cell components need to be post-dried before cell assembly to guarantee a low residual moisture content in the cells. Post-drying can be carried out in continuous roll-to-roll infrared dryers or discontinuously in vacuum drying ovens. The post-drying of whole coils in vacuum drying ovens is extremely energy-saving and gentle on materials, but dehumidification is limited by the structural and geometric boundary conditions compared to samples with freely accessible surfaces.

Therefore, a systematic investigation of the post-drying kinetics in vacuum drying ovens of graphite anodes and NCM622 cathodes with varying surface weights, coating widths, densities and coil lengths were investigated. At first, on the basis of findings from literature research and preliminary tests, an optimal post-drying process was developed to achieve a low residual moisture without impairing the microstructure. The different coils were then post-dried with this procedure to identify the influence of structural properties and coil geometry on post-drying kinetics. The electrodes were analyzed with regard to initial and residual moisture, rewetting and microcompression. In addition, tests on the adhesive strength, electrical resistance and pore radius distribution were carried out. The electrochemical performance was tested in pouch cells.

The analyses showed that the developed post-drying process can achieve a higher moisture reduction and a better electrochemical performance than the previously unsurpassed argon-vacuum post-drying [1] and is applicable for a wide range of structural properties and coil geometries. Nevertheless, different structural properties and coil geometries have a great impact on the absorption and release of moisture and thus lead to different post-drying results.

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Alternative binder and intrinsic conductive polymers in cathode production for LIB cells

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Epoxy resins and intrinsic conductive polymers are investigated as alternative binders for application in lithium-ion battery (LIB) cells. In conventional battery cathodes binders based on fluorinated polymers and copolymers, especially polyvinylidene fluoride (PVDF), are state of the art. From an ecological and economic point of view, the use of this polymer is problematic, as its processing requires usage of organic solvents such as N-methylpyrollidin-2-one (NMP), a harmful solvent which requires expensive efforts for safety reasons and equipment.

In this work, PVDF was replaced by an epoxy resin and NMP by methyl ethyl ketone (MEK). Additionally, lithium nickel cobalt manganese oxide (NMC622) was used as active material, carbon black (Super P) and graphite were used as conductive agents in cathode application slurry manufacturing. The new binder shows good handling during the slurry preparation, good curing behavior and thermal, chemical, mechanical and electrochemical properties adjusted to the battery specifications and the industrial process. Cell performance properties like C-rates and cycling reversibility were evaluated. Due to an optimized molecular structure of the binder, an increase in C-rate capability could be obtained. Initially, commercially available conductive polymers such as polypyrrole, polyaniline and poly(3,4-ethylendioxythiophene)-poly(styrolsulfonate) (PEDOT:PSS) are additionally used. Higher discharge capacity and lower capacity loss with increased number of cycles are achieved.

Our results highlight an alternative binder system in combination with conductive polymers in comparison to PVDF, cost-efficient and safe ingredient for LIB cell production without any use of toxic solvents. Our future developments will be economic and environmentally friendly battery assembly processes by a substitution of the toxic solvent (NMP) and the expensive and halogenated binder.

Preparation of silicon-carbon composites by fluidized bed granulation

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Silicon is a promising material for anodes in lithium-ion batteries because it enables a significant increase of specific capacity compared to graphite. However, silicon suffers from two main drawbacks, a large volume change during lithiation [1, 2] and its poor electrical conductivity [3]. In order to address these drawbacks, silicon graphite composites were developed to overcome these challenges. Therefore, the main goal of this study is to prepare composites aiming a defined particulate structure and mechanical and electrical properties by using silicon nanoparticles (x_{50} < 150 nm). The reason why nanoparticles are used is due to their smaller absolute volume change and thus, an improved composite and electrode stability. The production of these nanoparticles is carried out in a stirred media mill. In subsequent granulation silicon graphite composite particles are prepared by fluidized bed granulation. Within the granulation process, nano-sized silicon particles adhere on the surface of coarser graphite particles alongside binders and conductive additives. The addition of composite binder shows superior composite stability but leads to worse electrical and limited electrochemical performance. Conductive additives are added to overcome possible electrical transport limitations as a result of silicon's poor electrical properties. The composite particles are therefore studied in terms of electrical conductivity and mechanical stability. Finally, the volume expansion of composite particles has been investigated with dilatometry measurements and the influence of external pressure applied to pouch cells is evaluated with regard to their electrochemical performance. First electrochemical results of composites containing 8 wt.% silicon indicate good electrochemical stability in half cells.

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Optimization of electrodes based on Si@C for the next generation of LIBs

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Silicon is regarded as one of the most promising anode materials for next generation of lithium-ion batteries (LIBs) due to its high theoretical gravimetric capacity (~4,200 mAh g-1) comparing to graphite (372 mAh g-1). However, the backdrops, such as large volume expansion during lithiation process (up to 300 % of its original volume), pulverization and instability of SEI layer, lead to poor cycle ability of battery performance [1-3]. Several efforts have been made to overcome these issues by introducing nanostructured Silicon-Carbon composite (Si/C) and type core@shell (Si@C) materials as new anode active materials. The poor conductivity of silicon require the development and use of new conductive additives and binders that improve the cyclic stability and providing good performance at low cost.

In the past few years, graphene has been recognized as a promising anode material additive for improving the electrochemical performance of LIBs due to its excellent electrical conductivity, high specific surface area, and excellent mechanical flexibility [4-5]. For this reason, in TZE we are carrying out the optimization of the electrode based on Si@C by implementing new conductive agents based on graphene (as graphene nano-platelets, xGnP) into the electrode matrix. The selection of the components has a great influence on the viscosity and homogeneity of the electrode slurry. The viscosity determines the coating quality of the active layer and affects the surface loading. The homogeneity of the distribution of the components is a key factor to the electrical conductivity and their performance.

Electrochemical Characterization

Si@C (Nanomakers) was employed as the active material and mixed with graphene nano-platelets (XGSciences) and carbon black (CB, TIMCAL) for reference. Sodium carboxymethylcellulose (CMC) was used as a binder. The ratio of Si@C, conductive additive and CMC was 65:25:10 weight percent. The electrode slurries were prepared in deionized water using a mixer Dispermat.

The slurry was applied to a copper foil. The painted foil was vacuum-dried in an oven at 120 °C for 12 h. After drying, the foil was punched to make the working electrode. Swagelok cell was fabricated using the working electrode and lithium metal chips as the counter and reference electrode. The electrolyte was 1 M LiPF6 salt in ethylene carbonate (EC)-ethyl methyl carbonate (EMC) with 3:7 weight ratio and 2 wt% vinylene carbonate (VC) as additive. Glass Microfiber Filters from Satorius was used as the separator. Batteries were discharged/charged with the BASYTEC battery test system between 0.1 and 1.5 V vs. Li/Li+ at different current densities. Specific capacities and current densities were calculated based on the weight of the active material (Si@C).

Results

The first results show that the viscosity of the electrode slurry containing new graphene nano-platelets increased considerably with the addition of active material when is compared with the reference additive (Carbon Black). Rheological results suggest good slurry stability, which is important during electrode manufacturing in the industry. The coated active layer was homogeneous and the mechanical stability remained the same. The surface loading was similar or lower than the reference additive, while the total additive content in the slurry remained constant.

Electrodes Si@C/CB and Si@C/xGnP delivered an initial capacity of cycling around 1100 mAh g-1 at 1C, however, the influence of the conductive additive becomes noticeable in the electrochemical stability. While the cyclic stability for Si@C/CB decays from the beginning to stabilize after 100 cycles around 550 mAh g-1, the electrode Si@C/xGnP remains almost without change after 100 cycles with a coulombic efficiency with a capacity loss of only 8%. Taking into account that the electrochemical test was carried out without electrolytic additives with fluoroethylene carbonate (FEC), these results are excellent for this type of particles. The best performance of Si@C/xGnP has been attributed to the function of nano-platelets in providing continuous electronic pathways by linking most of Si@C particles together and offering the void space (interweaved with Si@C particles) to absorb the volume expansion in lithiation, thereby great reduction in the conduction network breakage during cycles and thus superior cycling stability [6-7].

Although the first results are very promising, full-cell testing, as well as spectroscopic studies, must still be performed to have a better understanding of the process.

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Post Lithium Storage - Processing of Sodium Ion Battery Electrodes

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The integration of fluctuating renewable energy sources into the future energy economy and the establishment of electromobility require new materials and technology concepts for powerful and sustainable electrical energy storage. In order to overcome current limitations of Lithium-ion battery technology, there are alternatives that no longer rely on Lithium. As part of the Post Lithium Storage Cluster of Excellence (PoLiS), scientists are therefore investigating the battery of the future and targeting sustainable systems based on Na, Mg and Ca ions. The central goal of the PoLiS Cluster is to develop a fundamental understanding of electrochemical energy storage in novel systems, to combine basic material properties with critical performance parameters and thus to create the basis for the practical use of post-lithium systems.

Sodium-ion batteries (SIB) could be one of these alternatives, especially for medium and large energy storage systems. SIBs are already being investigated and further developed on a pilot scale. The challenge consists in the development of active components for anode, cathode and electrolyte on the one hand and in the large-scale processing of the battery on the other.

In this work, the processing of SIB from the formulation of the active components for anode and cathode to coating and drying is investigated. The focus is on the relationship between drying conditions, formation of the microstructure, distribution of components and electrode properties as a function of different particle morphologies. The challenges of processing new materials and first results concerning the correlation of process conditions on the properties of electrodes for SIB are presented.

This work contributes to the research performed at CELEST (Center for Electrochemical Energy Storage Ulm Karlsruhe) and Material Research Center for Energy Systems (MZE). It is funded by the German Research Foundation (DFG) under Project ID 390874152 (POLiS Cluster of Excellence).

Investigation and evaluation of high-energy hybrid anodes containing different types of Hard Carbon

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Lithium-ion batteries are the leading technology for energy storage devices such as hybrid, plug-in and fully electric vehicles [1]. Intensive efforts have been made to improve the energy density of lithium-ion batteries [2]. In particular, the development and application of carbon-containing active material mixtures are promising prospects for use in high-energy anodes [2].

Main goal of this study is to investigate active material blends containing Graphite and Hard Carbon as the chosen anode materials. The motivation behind using blend anodes is based on the combination of the advantageous properties of each material. These differences are due to variations in microstructure (Graphite: layered structure; Hard Carbon: turbostratic structure; Figure 1). The usage of Hard Carbon should increase the structural stability, safety, and cell performance at low temperatures [2,3]. Therefore, anode active material blends with two different types of Hard Carbon particle size distributions (x50= 9 µm and x50= 5 µm) and different amounts of Hard Carbon (10, 15 and 20 w-% of Hard Carbon) are compared. The materials are dispersed and the structures are investigated on particle level as well as on coating level. Hence, a formulation strategy which is adapted to the particular structures of the active materials has been established. The different blend slurries are processed and characterized with regard to their particle size distribution and rheological properties, which enables to visualize differences between the materials and allow an initial estimation of the further processability. To have a closer look on the different Graphite/Hard Carbon blends, the electrodes are also analyzed with regard to mechanical properties like adhesion strength, electrical conductivity and cell performance. The electrochemical performance of the anodes is represented with a surface area capacity of 6 mAh/cm². For example, this investigation shows that the addition of Hard Carbon leads to an improvement of the electrical conductivity. Furthermore, the influence of the active material due to the electrode structure properties can give an outlook to a potential process scale-up.

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Influence of film thickness and calendaring process on the coating properties and electrochemistry of cathodes for Sodium-Ion Batteries

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Materials which are used in lithium-ion batteries like cobalt and lithium, increasingly cause problems due to their limited availability and sustainability. Therefore, alternative systems like sodium-ion batteries are investigated to cover applications where the highest performance is not required.

When using larger sodium ions as the charge carrier, compared to lithium, higher stresses arise in the active material due to the volume change during cycling. The magnitude of the stresses can be reduced by applying porous nanostructured particles. With lithium-ion cells, it has already been demonstrated that porous nanostructured cathode particles show improved rate capability and cycle stability. However, the processing of these porous particles into electrodes poses some challenges, such as low adhesion strength, high electrode porosity and binder migration effects.

The focus of this work is how the process parameters like slurry formulation, film thickness and calendaring process affect the coating properties and the electrochemical behaviour of new porous nano-structured Na3V2(PO4)3 (NVP) active materials for post-lithium batteries.

The contribution also gives practical insights of the interaction of various inactive materials (conductive additive and binder) with the NVP particles.

Influence of intensive dry mixing of graphite based anode powders on slurry, electrode and electrochemical properties in lithium-ion batteries

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Intensive dry mixing of anode powders can significantly influence the structure and the interaction of the components. Especially the structure of the carbon black agglomerates is influenced by the intensive dry mixing beginning with a desagglomeration to the point of creating a mechanically stable connection between the carbon black and the graphite active material when processed together. This leads to changed properties on different production levels like slurry, electrode and cell. Controlling the level and the nature of structural change in the powder allows the creation of favourable properties of intermediate products in following process steps as well as favourable properties of the lithium ion cell.

Regarding cathodes, intensive dry mixing has shown significant changes in properties of all intermediary products from powder to cell. Despite a decrease in powder and electrode conductivity due to the coating of carbon black particles on the surface of active materials, electrochemical results have shown a more stable long term cycling performance. So far no research has been published investigating the influence of intensive dry mixing regarding anode powder.

In this work we conducted process studies on intensive dry mixing of graphite based powder mixtures using a ring shear device. In the scope of this the tangential velocity and therefore the mechanical stress has been varied as well as the ratio of carbon black in the intensive dry mixing step. The resulting intermediary product features have been investigated using e.g.: viscosity, particle size distribution, el. Conductivity, cycling performance and structural properties using SEM images. Similar to the cathode findings our results show significant property changes across the whole process chain.

A reliable large-scale implementation of water-based slurry technology for production of high-performance lithium-ion batterie

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Leclanché GmbH

Leclanché offers to the energy storage market two kind of rechargeable lithium-ion cells: graphite/NMC cells for energy intensive applications, and titanate/NCA for leading performance in long-life and rapid charge applications. Both cell types in pouch format and produced entirely in Willstätt, in Germany, and assembled in battery modules in Yverdon-les-Bains, in Switzerland. Such cells are manufactured on the same line function of the customer requirements for energy solutions.

The cell assembly starts with the electrode manufacturing exclusively using a water-based binder (WBB) process. This is a simplified process in comparison to the organic solvent-based process, leading to a minimum environmental impact, reduced end cost of the cell manufacturing and as well improved cell performance. While the technology used for anode fabrication is worldwide rather common, the cathode water-based technology is not well-known or understood. This makes Leclanché one of the global leaders of the WBB technology.

Our main focus lies on the development of the G/NMC cells containing NMC cathodes with high Ni content for an improved cell energy density and cell capacity (>60 Ah) required for e-transportation energy storage solutions. The manufacturing of these electrodes is however more difficult in general, due to complications of active material chemical and physical properties, e.g. higher intermixing rate of Li-ions with Ni-ions in the NMC lattice, due to similar ionic radius, yielding to irreversible structural changes during intercalation/deintercalation processes (charging/discharging of a cell). In particular, the problematics of the water-based slurry development is its stability with time due to variation in physico-chemical properties. Its instability could lead to a lower electrode quality, adhesion and cohesion issues, current collector foil affected by corrosion, etc. Since the particle distribution of active material plays an important impact on the behaviour of the whole mixture, formulations containing different binders and additive components ratio were developed.

Currently we achieved the development of a reliable large-scale implementation process from the lab towards all production steps by transferring the R&D know-how to the industrial scale towards a safe and performant cell with high energy density and/ or for high power applications. The lifetime tests on this cell at ca. 1C/1C continuous for a 100% DoD validate over 4000 cycles at room temperature conditions.

Influence of binder on the structure and performance of anodes

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The development of environmentally friendly, safe and cheap lithium-ion batteries (LIB) including a significant increase in energy density and cycle stability is a global challenge. Depending on the application, LIB have different specifications like mass loading and area capacity as well as various active and inactive materials. As a part of the inactive components, polymers (so-called binders) are essential to bind the particular components to each other and to the current collector. They are influencing the mechanical properties and structure of electrodes directly, which are a main lever for an increase in energy density and cycling stability. On the other hand, polymers have some natural drawbacks regarding their material properties like no electrochemical activity and, depending on their molecular structure, a poor (electrical/ionic) conductivity. While the electrode structure and thus, the electrical and ionic conductivity can be optimized by adjusting process and formulation parameters, the electrode production is highly influenced for example by the cross-linking properties of the polymers. Therefore, the knowledge about the binder properties and their interaction with the other materials are crucial to optimize the performance of LIB.

This study focuses on the interaction of various binders (e.g. carboxymethylcellulose (CMC), alginate (ALG)) and the influence of their molecular masses on the structure of the resulting suspensions and anodes as well as the corresponding performance. Regarding comparability, most parameters like recipe, manufacturing processes and mass loading of the coating are held constant. The electrodes consist of 93 wt.% artificial graphite, 1.4 wt.% carbon black, 2.8 wt.% styrene-butadiene rubber (SBR) and 2.8 wt.% of the variating binder and are manufactured discontinuously in industry-related processes. Following the manufacturing process, the resulting structural parameters of the suspensions and electrodes are determined (e.g. rheology, porosimetry, adhesion force) and compared. The rheological behaviour represents the importance of this study. While the difference of the two pure substances CMC and ALG in solution is very small, they behave very differently in a battery suspension. Furthermore, the alginates differs more strongly than assumed. The effect can be explained by their molecular structure. ALG contains a higher carboxylic amount of mannuronate than guluronate which leads to a more linear chain structure than CMC. During shearing, the polymer chains of ALG are stretched more than CMC and the viscosity decreases. The difference in rheological behaviour as well as the binding mechanisms have a big impact to the electrode structure and cell performance. Summing up, the correlation of binder properties on the surface interaction mechanism and will be correlated to suspension and electrode properties as well as the resulting electrochemical behaviour.

Edge formation during the coating process of li-ion battery electrodes

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In today's production of battery cells, the slot-die coating process in large roll-to-roll systems is state of the art. In addition to the known limiting coating defects, such as air entrainment and low-flow streaks, there is a formation of elevated bulges on the edges of the coating, which can cause damage in subsequent process steps. In the industrial continuous cell production, edge elevations are removed except at the position of the current collector, resulting in high material waste. During calendaring and rolling up electrodes, edge elevations at the current collector can lead to an inhomogeneous force distribution over the width of the coating, which causes waves and cracks at the edges of the electrode. This problem is intensified especially in the production of thick electrodes. The dimensions of the edge elevations can be minimized by a combination of suitable internal fittings in the slot die and an adjustment of relevant process parameters such as the gap between slot die and current collector and the wet film thickness of the coated electrode. To be able to minimize the edge elevations, it is important to develop an understanding of the process.

In order to reduce edge elevations, a procedure has been developed, in which the internal geometry of the slot die is adapted in a suitable manner. In this work, the influence of material properties, process parameters and the internal geometry of the slot die on the edge formation was investigated experimentally. With the knowledge gained, the development of edge formation shall be predicted.

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Simulation of water mass transport during the post-drying process in the production of lithium-ion batteries

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For competitive battery cells, an important prerequisite is energy savings in the cell production. An essential cost factor in the manufacturing process of Li-ion batteries poses a subsequent post-drying process. In this process, moisture adsorbed from the air gets removed from the compounds of the battery by a high energy input. Otherwise, the adsorbed moisture reacts with the electrolyte in the operation of the battery, what leads to its degeneration. Literature has revealed a connection between electrochemical performance and the remaining moisture content. In order to remove the moisture cost efficiently from the compounds of the battery, this process step needs to be understood completely. Therefore, a precise and comprehensive simulation along with knowledge of the sorption equilibrium of water and the kinetics of mass transfer reveals optimization potential of energy consumption and process acceleration.

This work develops a simulation tool which describes the water transport in porous electrodes during post-drying. As a physical basis for transport phenomena, sorption equilibria of the compounds of a Li-ion battery have been ascertained by means of a magnetic suspension balance. The simulation allows the dynamic consideration of a variety of process parameters (i.e. temperature, partial pressure of water and electrode composition). Moreover, from these simulations first conclusions have been drawn regarding the limiting diffusional resistance in the drying process. The post-drying set up of a research and production facility provides data to validate the simulation tool.

This work contributes to the research performed at CELEST (Center for Electrochemical Energy Storage Ulm Karlsruhe) and Material Research Center for Energy Systems (MZE). The authors would like to acknowledge financial support of the Federal ministry of Education and Research (BMBF) via the ProZell cluster-project “Sim4Pro” (Grant number: 03XP0242C).

The importance of passive materials in thick Li-ion battery electrodes

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Due to their outstanding energy and power density, Li-ion batteries are widely used in portable electronic devices and electric vehicles. The porous composite of a Li-ion battery electrode generally consists of active material, conductive carbon and polymeric binder. A microporous phase formed from carbon black and the binder (CB domain) is distributed in the macro-pores of the active material network and provides better mechanical stability and electronic contact. However, at the same time the CBD increases the tortuosity of Li-ion transport pathways in the electrolyte. At high current densities, this increases mass transport limitations and reduces the performance of the battery cell. It has already been shown that the production process has a significant effect on the morphology and distribution of the CBD. For instance, harsh drying conditions can cause binder migration to the electrode surface, which amplifies transport limitations and performance losses.

In our contribution we present results of pore scale simulations of Li-ion batteries, which explicitly consider the morphology and distribution of the CB domain. In these simulations we study 3D realizations of NMC cathodes created by a 3D stochastic microstructure generator with varying density and thickness. In a first step we determine effective conductivities of the virtual samples with varying CB distribution and volume fraction. This data provides insight on limiting processes during operation of the battery cell and is important input to volume-averaged models of the Newman-type.

In a second step, we simulate the electrochemical performance of the virtual electrodes with an extended version of the “Battery and Electrochemistry Simulation Tool” (BEST) for microstructure-resolved simulations of Li-ion batteries which was developed in our group. In order to accurately capture the influence of the CB domain on battery performance we extend our framework considering both the transport of electrons in the conductive carbon network as well as Li-ion transport in the available pore space. This approach allows us to evaluate the effect of inhomogeneous CB distribution arising from different conditions in the production process and gives directions for both electrode and process optimization.

Cell Assembly

Continuous processes for the high-throughput cell assembly of Li-Ion batteries

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Due to their complex value chain, Lithium-ion batteries (LIB) are the most important cost factor in the production of an electrically powered vehicle. To meet the growing demand for LIB in the automotive, cost-efficient and highly productive manufacturing technologies for mass production must be available in a timely manner. The objective of the project "High throughput processes for the production of lithium ion batteries (HoLiB)" is the development of new technologies and the reduction of non-value adding times within the process chain to enhance productivity in cell manufacturing. The scope of HoLiB are the process steps cutting, stack assembly and contacting. This poster presents the HoLiB project and shows first results with regard to the individual sub-processes.

The first of the sub-processes is the cutting processes. Regarding this process, the aim of the project is the development of a high-speed laser cutting process, which projects and cuts the entire electrode contour onto the material. In this poster, an approach for the process design is presented. For the stacking of the electrodes a paddle wheel is designed which replaces the pick-and-place process of a robot by a continuous handling operation. The construction faces several problems, e.g. the design of the paddles to ensure a handling process, which is both damage free and capable for high-speed processes. The setup of a flexible simulation model assists the verification of the design. A modification of the feeding unit allows a continuous supply of the paddle wheel. For the subsequent contacting of the electrodes, the project aims to develop a laser micro welding process in one process step. First tests for the welding and handling of the thin foils show promising results.

Additionally, the linkage of the individual process technologies has the potential for a further increase of the production speed. To implement the linkage, the process interfaces are defined in a detailed list of requirements.

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Welding of electrode-separator assemblies using blue laser radiation for the high-speed production of Li-ion battery cells

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Increasing productivity in cell manufacturing is essential to reduce manufacturing costs and to meet the increasing global and national demand for lithium-ion batteries for electric mobility. In current cell production, either time-consuming pick & place processes or winding processes that damage the material and thus reduce quality exist in the area of stack formation or winding of electrode-separator composites (ESV). In the field of packaging, innovative solutions for continuous and web-bound separation and further processing of electrodes are currently lacking. In particular, the connection technology of the individual layers of cathodes and anodes poses a challenge here.

In order to maintain the production cycle for high-speed stack formation, a joining process is required that can meet the high demands on process speed and robustness. The laser beam as a non-contact tool is predestined for this. The aim of this work is to reliably join up to 20 copper foils, each with a thickness of 10 µm, using blue laser radiation.

For this purpose, copper foils in the format of common pouch cells are cut and positioned in a pressing device. For the joining of the foils different laser parameters are tested. The variable parameters include the laser power P, the feed speed v and the spot size dS. By varying the spot size, the intensity on the workpiece can also be influenced. The resulting samples are examined with regard to seam quality and bonding surface. For this purpose, metallographic transverse and longitudinal sections of the samples are prepared and evaluated.

The metallographic sections show that the joining of copper foils with blue laser radiation is possible and is suitable for the production of stacked laminates for the production of battery cells. Pores were visible in some of the sections. This is mainly due to the contact pressure of the foils during the welding process.

Influence of the porosity ratio on the performance of Li-ion cell by using PVdF-based separator

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Although the separator are not active components in batteries, it plays a key role in Li-ion transport from anode to cathode during discharge and back again during charge, while preventing short circuits between the positive and negative electrodes. Separators influence cell costs, life, performance and safety.

Most commercially available Li-ion battery separators are polyolefin based on polyethylene (PE) and/or polypropylene (PP). These separators are generally chemically stable, highly porous, and low cost. However, they present low wettability toward the electrolyte and poor thermal stability, which limit the performance of the Li-ion battery. Furthermore, a stretching process is usually involved in the production of conventional polyolefin separators to generate porous features. Application of the stretched separators at elevated temperatures normally leads to separator shrinkage resulting from the re-organization of the elongated polymer chains, and, eventually, may cause battery shortage.

Separators based on polymers with high affinity to electrolytes, such as, PVdF-HFP, and, processed casting-knife as low cost, simple and scalable wet processes could be a potential alternative to conventional ones. Here, the effect of surfactant content on the porous structure of PVdF-based polymer separator was studied by testing their performance on a Li-ion cell configuration.

Selected solutions containing different PVdF-HFP/surfactant ratio were prepared and membranes obtained by casting-knife processing. After that, they were characterized by porosity, thermal and chemical stability, ionic conductivity and electrolyte wettability. The performance of obtained separators in Li-ion batteries were tested by charge-discharge tests in the voltage range from 2.5 to 4.0 V using LFP/graphite as positive and negative electrodes, respectively, and, 1M $LiPF_6$/EC+DEC (1:1), as electrolyte.

Results showed that surfactant content has a clear effect on the pore size distribution of the final membrane and therefore on its properties as separator in Li-ion batteries. The use of surfactants as non-solvent agent in PVdF-HFP membranes preparation by phase inversion method allows the preparation of tailored polymer membranes with narrow pore size distribution and high wettability in a single-step and scalable process.

Investigation of the influence of different electrolyte solvents and the ambient medium on the wetting properties of cell components

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With the increasing importance of electrical storage technologies for mobile and stationary applications, the need for improved productivity to increase throughput and reduce manufacturing costs is growing. In current cell production, the electrolyte filling of lithium-ion batteries and the subsequent wetting are essential process steps and represent the interface between cell assembly and its formation. The electrolyte filling and wetting process presents a high potential for throughput increase and cost reduction through a reduction of the otherwise usual long storage times. Best practice solutions are currently being used. However, it has hardly been systematically analyzed, which mechanisms dominate filling and wetting, and how these can be accelerated.

To gain a better understanding of the wetting mechanisms, the wetting behavior of different cell components has been analyzed in the first step. The electrodes and separator are characterized by a porous structure whose impregnation behavior is decisive for the wetting of the cell stack. The wetting is represented by the contact angle between a solid and a liquid interphase, which can be determined by a measurement with a modified Washburn method on a tensiometer. For the solid phase, the electrode and separator materials were used in this study, on which the wetting of large-format battery cells will be considered later. As a liquid phase, the different solvents found in common industrially used electrolytes are investigated. A further influencing factor was taken into account since the temperature of the solvent affects the viscosity and thus directly on wetting.

In further experiments, the interrelationships are investigated by first using electrolytes as liquid phase and secondly a variation of other influences, such as the degree of calendering or post-drying of the electrodes. The results of the measurements provide deeper insights into the wetting process, especially for large-size lithium-ion batteries.

Method for the Production of Reproducible Lithium-Ion Coin Cells

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Coin cells are often used in research and development of innovative battery materials. Due to the simple structure and the possibility of manual production, coin cells enable a quick and inexpensive examination compared to larger cell formats. The structure of coin cells used for lithium-ion batteries (LIB) is often poorly documented in the literature. The comparability and traceability of the results presented is only possible to a limited extent or not at all due to the lack of a standard in coin cell production. For this reason, the focus of the method for coin cell production presented here is on the reproducibility of the cell performance. With regard to this focus, the statistical settings were used to systematically change the parameter settings in order to subsequently determine functional relationships and interactions between the most influential factors. This includes the amount of electrolyte, the electrode ratio, the spring type (disk and wave spring) and the number of separators. Using a full factor plan, it could be shown that a coin cell with a disk spring, one spacer and two separators achieved the highest reproducibility of the performance. During the preliminary tests, it was also found that placing the cell materials in the electrolyte for 24 hours before assembly significantly improved the handling and thus the reproducibility of the assembly and performance. Most recently, the state of research on coin cell assembly and the newly gained knowledge were used to develop a step by step method that includes both the preparation of the cell materials and the assembly.

Battery Production 4.0

Identification and selection of variables in battery cell production for analyses of process improvement using the example of dry coating with the help of Failure Mode and Effects Analysis (FMEA)

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Increasing efficiency is an urgent necessity for ensuring the competitiveness of battery cell producers. In order to improve efficiency, it is necessary to understand the many different dependencies within cell production. However, this is not yet the case. There are different approaches in the context of Industry 4.0 that want to use the possibilities of digitisation to uncover these dependencies. As with all other approaches to process improvement, a prerequisite for these approaches is that the variables relevant to the process are identified and selected. Various tools are available to identify and select these variables:

1.Ishikawa diagram
2.Process flow chart
3.Influencing factors-target variable-matrix
4.Failure Mode and Effects Analysis (FMEA)

Especially the first three approaches are only conditionally suitable for mapping the complex interrelationships of battery cell production, since they can be applied to individual process steps but not to complete process chains. FMEA, on the other hand, has already been applied to the selection of variables for improving battery cell production. However, this approach does not make use of the possibility of identification with the help of FMEA. However, existing approaches from other industries show that an application for this seems possible. The approach presented here therefore examines how a combined identification and selection of influencing variables can be carried out with the help of FMEA using the example of the dry coating of electrodes to ensure that all relevant variables of the process are identified and selected. Only if this is the case, the approaches of Industry 4.0 based on this can achieve their full effect.

Evaluation of production processes and quality assessment of Li-Ion batteries using microscopy and machine learning

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Electrochemical energy storage will play a significant role in the necessary reduction of ecologically harmful carbon dioxide emissions. Especially Li-ion batteries are important for storing renewable energy to balance out fluctuations in producing and consuming of energy and for providing a more sustainable mobility with emission free or reduced vehicles. The production of Li-ion batteries is energy consuming and requires critical resources. Therefore, it is important to reduce the scrap rate during production and use the raw materials in an efficient way. To overcome these challenges a high production quality has to be assured over the whole production process, which also helps to increase the safety and durability of the batteries. Many quality related issues occurring in Li-ion batteries can be seen in the microstructure. The investigation of polished cross sections of Li-ion batteries with light microscopy is a powerful tool to identify relevant defects. Object based machine learning algorithms allow the processing and automated defect detection with large amounts of image data. With this approach, we can gain information about the spatial and statistical distribution of different defects within Li-ion batteries. We demonstrate our method on commercial 18650 cells with NMC-622 cathodes and graphite anodes. We are able to detect various defect characteristics and identify the most relevant regarding quality and stability of production processes. We show how specific failures like particle contamination vary between different production batches. The combination of light microscopy images and the analysis using machine learning algorithms is a powerful tool that can help to improve the quality of Li-ion batteries and the production processes. The application is also suitable for benchmark analysis of different suppliers or incoming inspection.

Process Analytical Technology for Industrial Battery Production

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tec5 AG

Process analytical technology is used in manufacturing and processing industries for automated physical-chemical analyses of raw materials, intermediate and final products.
The objective and the motivation for continuous monitoring and control is to ensure product quality, to achieve optimization of production processes and to fulfil compliance with relevant regulatory guidelines.
Particularly, optical spectroscopy offers established and well-proven methods for fast and non-contact ingredient analysis of chemical compounds and element contents. Various spectrometer systems based on UV-VIS-NIR, Raman and Laser-Induced Breakdown Spectroscopy have emerged as standard procedures in laboratory applications. When transferring proven methods into scalable industrial processes, laboratory systems can only partially be integrated directly into the process.
For 24/7 operation, outstanding system stability and high availability is required. This is achieved by using dedicated modules for data acquisition, processing, and process communication. Special attention is paid to the selection of components to ensure long lifetime and high robustness as well as to comply with to the regulatory requirements.

Herein we will give an outlook on the advantages of utilizing spectrometer systems as process analytical technology in industrial battery production – from electrode production to cell production and during cell conditioning. Examples will be presented for tracking of the process during material production – for example phase analysis within the quality control of material syntheses (e.g. solid electrolytes, active materials). Integration of inline methods in production facilities (e.g. synthesis mill, thin film processes) and investigation of material degradation in subsequent process steps (e.g. coating plant).

Module & Pack Design & Safety

Characterisation and Comprehensive Analysis of Protective Safety Devices in Pouch Cells on Cell Level

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The electrification of the mobility sector challenges both entire industries and application-oriented researches. The chief objective is to increase the energy density of Lithium-Ion Batteries (LIB) resulting in higher ranges of electric vehicles. Meanwhile, the combination of new active materials and easily inflammable toxic electrolytes yield directly in electrical, chemical and mechanical safety issues. For instance, external influences such as short circuits, overheating and mechanical deformations in crashes or internal influences because of production errors can trigger critical safety situations leading to hazardous fire, environmental pollution and casualties in the most serious case.

However, to counteract these critical circumstances in cylindrical as well as in prismatic cells, additional devices increase the safety on cell level. For instance, positive temperature coefficient (PTC) resistors, current interrupt devices (CID) or safety valves protect against overheating. In addition, printed circuit boards (PCB) deployed as external fuses, shutdown separators and overcharge-protecting additives in the electrolyte improve the overall safety by reducing harmful chemical reactions within the cell. In comparison to pouch cells, similar safety mechanisms are not existent on cell level yet.

Therefore, the research's aim is to identify potential safety devices, which are suitable for pouches on cell level and to integrate them to the cell. Experiments draw particular attention to joining and designing issues, while ensuring the specific requirements (joining and design parameters, compatibility with the electrolyte and functionality after implementation). First results show the high potential of the integrated PTC: it is joinable with the conventional joining techniques, attachable to cathode or anode and most important it displays a certain resistance to the dimethyl carbonate solvent.

Electro-thermal optimization of safe fast charging strategies

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The fast charging of lithium-ion batteries is one of the main challenges for the acceptance of electric vehicles. Moreover, the state of the art formation with slow charging rates during the battery production cause high costs due to long process times. This contribution presents a systematic method for developing voltage and temperature optimized fast charging strategies. Higher temperatures are increasing the electrical and ionic conductivity of lithium-ion batteries but too high currents and temperatures need to be avoided in order to guarantee safe charging. With the help of experimental test-cells and a battery equivalent circuit model, the maximum charging current in dependency of temperature und state of charge are identified. Based on the parametrized electro-thermal battery model and different conditions (e.g. maximum temperature or current) optimized safe fast charging current profiles are simulated, compared and experimental tested. The results show a significant reduction of the charging time with increased temperature while avoiding the maximum temperature. This model-based approach of characterizing the fast charge ability is able to design fast charging strategies for a given cell configuration without causing safety issues like lithium-plating or critical cell temperatures.

Production of Solid Polymer Batteries

Scalable tape-casting of Lithium thiophosphate (β-Li3PS4) solid electrolyte and composite cathodes for all-solid-state batteries

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All Solid-State Batteries (ASSBs) have gained a progressive demand to expand their applications as safe and efficient power supply for Electric Vehicles (EV). In addition to their comparably high Li-ionic conductivities, sulphide-solid electrolytes can be prepared by low-cost methods as other solid electrolytes. For a scalable ASSB-mass production, the solvent-based roll-to-roll fabrication route is highly favorable as a high-throughput technique than the dry-mixing procedure of pelletized ASSBs.

Therefore, we are developing and scaling up a tape-casting process route of β-Li3PS4 solid electrolyte/separator and LiNix-CoyMnx-yO2 (NCM)-Li3PS4 composite cathodes. Li3PS4, NCM cathode active material and conductive carbon were mixed and dispersed by a dissolver with polymeric binder/s (≤3.3 wt%, dissolved in p-xylene solvent). The obtained slurry was coated by the doctor-blade technique on aluminium foil to obtain the composite NCM-Li3PS4 cathode film. The Li3PS4 separator was prepared by dispersing Li3PS4 powder and polymeric binder/s (≤5 wt%) in p-xylene, then the produced slurry was directly casted on the composite-cathode film. So far, the results indicate that cathode films prepared using 3.3 wt.% HNBR binder as well as Li3PS4-separator films prepared using HNBR and Polyisobutene binders (2.5/2.5 wt/wt%) are compact films. The obtained NCM-Li3PS4@Li3PS4 films were compressed at different pressures and temperatures before cycling versus Indium anode. Electrochemical tests and cycling evaluations along with in situ EIS measurements of as-assembled ASSBs were conducted in a press-cell at different pressures, in addition to mechanical tests, ex situ SEM and XRD investigations.

Effect of Microstructure on Ionic Conductivity of Polymer All-Solid-State Electrodes

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Solid electrolytes in lithium-ion batteries promise increased energy densities, fast charging properties and advantages in terms of safety due to the non-flammable materials. Besides the electrochemical properties of the materials used, the chemical processes are limited by the transport mechanism and transportation routes of charged species, which effect the cell performance significantly. The size distribution and the composition, which needs to be balanced in terms of transport characteristics and capacity, affect the electrode's inner structure and thus the charge transport. Simulations can provide an inside view in regard to advantageous transportation routes obtained by low electrolyte tortuosity and a percolated conductive network as well as a high contact area between active material and electrolyte.

The presented study investigates the structural properties of model electrodes with varied fractions as well as different particle size distributions. In order to focus on ionic transport routes, no conduction additive was used and as model active material electrochemically inert SiO2 particles were incorporated. The simulations executed with GeoDict 2020 (Math2Market) provide the tortuosity and effective diffusivity which are used to calculate the ionic conductivity by the model of Bruggeman and the Nernst-Einstein-equation.

The calculated ionic conductivity values show the same dependencies as function of the active material content as the measured conductivity obtained from pressed PEO/LiTFSI-electrodes. Simulations show, that tortuosities derived by Bruggeman are overestimated, especially for high active material contents as the model assumes an ideal solution as well as a fixed dependency of tortuosity and conductivity. The comparison of electrode characteristics to simulated results show the restrictions of the applied model calculations, provide insight into the electrode structures and validate the simulations to enable predictive studies on optimization.

Influencing the conductive pathways within polymer and hybrid electrolyte cathodes

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Solid-state batteries emerge as an option for next-generation batteries promising higher performance and safety than traditional liquid electrolytes [1]. Here, organic polymer based and inorganic electrolytes are investigated in composite cathodes, to combine the high ionic conductivity of ceramic-based solid electrolytes and the mechanical performance of polymer-based solid electrolytes [2, 3]. Aiming to increase the power and energy density the composite cathodes are 3D-structured by additive manufacturing allowing gradient structures that promote the ionic and electric conductivity. This process requires precursor particles consisting of active material, electrolyte and conductive additive. In this contribution, we present solvent-free structuring methods for the processing of solid electrolyte-based cathodes.

The overall electrochemical performance is limited by the slowest transport mechanism within the cathode. Therefore, it is important to build up sufficient electrical and ionic conductive pathways and understand how the process parameters affect the conductive additive distribution. The process chain starts with a dry mixing step to uniformly distribute the cathode components and adjust the carbon black agglomerate size. Mixing parameters like temperature and rotational speed are varied and effects on electrical conductivity as well as porosity are investigated. Additionally, NCM622 and LFP as active materials and different polymer electrolytes as well as LATP-polymer hybrid electrolytes are evaluated with respect to their effect on best process parameters. Afterwards, the cathode precursors are pressed and calendered to form a dense compound and reach the target thickness. Finally, the cathode is laminated onto a current collector and further processed to a pouch cell. The electrochemical performance of the manufactured cathodes is measured using lithium metal anodes and an external pressure during cycling. The all-solid-state pouch cells with LFP as active material reach approximately 54 % of the theoretical capacity at 1C and 80 °C.

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Laser cutting process of lithium metal foil for all-solid-state battery systems

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In order to a largely establishing of electric vehicles in the market an increase of energy density is needed. All-solid-state batteries are promised to be the next generation battery systems. While on the cathode side versatile materials and mixture recipes were examined, the anode side commonly applies to lithium metal. The processing of this material is a demanding challenge caused by both the strong adhesion behavior to other materials and the highly reactive character of lithium as an alkali metal.

The commonly used separation process of lithium metal foils for battery application is a punching separation, which caused an abrasion of the cutting edge on the cutting die. A mechanical punching separation of thin lithium-foils yields to additional challenges in case of size accuracy or contamination of the cutting edge. A contactless separation process like laser cutting could solve this problem.

For this research an improvement for the separation of the anode for battery applications laser cutting processes are investigated. To evaluate which laser cutting parameters leads to cutting edges with a high surface quality, different parameters in terms of average laser power, cutting speed and pulse repetition rate are investigated. The variation of the laser cutting parameters takes place, while keeping the line energy. Previous investigations show good results for thicker lithium foils with a ns-laser system [1]. Now more parameters, materials and a ps-laser system are take into account.

For this research, pure lithium metal with a thickness of 20 µm and lithium metal coated on a copper foil also with a thickness of 20 µm are established. For the separation process, a nanosecond laser system and a picosecond laser system (both with a wavelength of 1064 nm) are used.For the separation process with the nanosecond laser, a combination of low pulse repetition rate and high cutting speed shows the best results. Under optical properties such as melting formation, melt width and gap width, a high-quality cutting edge is achieved. In comparison to the nanosecond laser, the picosecond laser leads to a reduction of the heat affected zone, while using the same line energy.

In addition to the surface quality, for battery applications electrochemical quality is highly important. Further investigations are carried out to evaluate the influence of the laser cutting process on the electrochemical performance.

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Upscaling of mechanochemical syntheses of sulfide-based solid electrolytes

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All-solid-state batteries (ASSB) are considered as further development of lithium-ion battery technology due to their potentially superior properties [1, 2]. In order to produce competitive cells with high energy density as well as thermal and mechanical stability, the choice of materials at the beginning of the value-added chain is a main key. Currently, there are many challenges for upscaling synthesis processes of solid electrolytes (SE). Based on high educt and- as a result of small-scale processes- high SE costs, ASSB have yet to be established in an industrial scale. Thus, our work focuses on gaining a deeper understanding of process-product relations and evaluates and establishes new process strategies for the production of SE.

Thiophosphates as Li3PS4 or Li6PS5Cl have attracted broad interest as SE because of their high Li+ conductivity and compliant mechanical properties [3]. Their syntheses can be performed by high energy ball milling, but as the reaction mechanisms are still not well understood, it is important to acquire extensive knowledge of the process-product interactions. The mechanochemical synthesis of glassy Li3PS4 in planetary ball mills is currently taking up to 30 hours to achieve a high product quality. Considering the required cooling periods due to the used equipment, process times of even up to 5 days are reported in the literature [4].

The objective of this work is to optimize the synthesis process by systematic variation of parameters, such as grinding media or rotational speed. By the use of temperature-controlled mill types and high energy input, the process times have already been significantly reduced to under 20 hours. To further investigate the process-product relation, the SE are characterized by X-ray diffraction, Raman spectroscopy and scanning electron microscopy. The conductivity is determined by electrochemical impedance spectroscopy and results show values of 0.3 mS/cm for Li3PS4 and 0.9 mS/cm for Li6PS5Cl.

Based on the obtained insights, the synthesis procedure will be adapted for the upscaling in suitable ball mill types such as vibrating mill and stirred media mill and thus facilitate the industrial production of ASSB.

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The FestBatt-Cluster of Competence on Solid-State Batteries

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Solid-state batteries (SSBs) are currently regarded as a very promising electrochemical energy storage technology. This concept is based on removing a liquid electrolyte commonly found in conventional lithium-ion batteries (LIBs) and exchanging it with a solid ionic conductor. With the right materials and material properties, this technology is expected to offer higher storage capacity, shorter charging times and more safety in the long-term compared to conventional LIBs. However, before SSBs can be commercialized, several fundamental material issues need to be solved and questions regarding the scalable synthesis routes for materials, as well as production technology need to be answered.

The "FestBatt" cluster of competence on solid-state batteries works on an interdisciplinary basis to identify, produce, upscale, and process suitable solid electrolytes for SSBs. The aim is to create the knowledge required for the evaluation of new materials, their synthesis, the production as well as the upscaling of suitable solid electrolytes. 21 working groups at 12 scientific institutions throughout Germany are working on this and form 5 so-called “platforms”. Three of these, the material platforms, focus on solid electrolytes from the material classes “Oxides”, “Thiophosphates”, and “Polymers”. Here, new materials are explored, scalable synthesis routes are developed, and cell tests on SSBs based on these materials are conducted. The two remaining method platforms “Characterization” and “Theory and Data” support the material platforms with advanced and specialized characterization techniques as well as theoretical simulations on multiple scales. The platforms in the FestBatt Cluster of Competence on Solid-State Batteries hold and continuously extend the knowledge required to bring SSBs closer to possible applications.

Electrode, Cell and Module Diagnostics During Production

Large Amplitude Oscillatory Shear Rheology of Electrode Slurries

Carl Reynolds
University of Birmingham

Electrode coating is a key process in battery manufacture and the microstructure, adhesion and presence of defects in the electrode coating can have a large impact on battery performance. Rheological testing is one way to characterise electrode slurries and make predictions of their coating behaviour. Standard shear testing only provides the slurry viscosity at the applied shear rate, which gives little insight into the underlying behaviour. Oscillatory testing provides the more useful, elastic and viscous moduli (G′ and G″), but is often performed at low strains in order to keep the sample in the reproducible linear viscoelastic region, which is not representative of coating conditions. Here we address this problem for electrode slurries by using large amplitude oscillatory shear rheology, studying the trend of rheology with increasing strain. As well as the elastic and viscous moduli, the third harmonic is extracted by Fourier transform to give G3′ and G3″ which give information about the response of the material to strain and shear rate respectively. Through this method additional structural information can be extracted, as well as a better understanding of the rheological behaviour of the slurry, under conditions closer to coating.

Continuous non-destructive quality monitoring of a battery suspension or dispersion by inductive electrical impedance and ultrasonic spectroscopy

Marcel Wild, Jann Seeba, Dr.-Ing. Sebastian Reuber, Martin Schulze, Martin Oemus, Prof. Dr.-Ing. Henning Heuer, Dr.-Ing. Mareike Wolter, Prof. Dr. Ing. habil. Alexander Michaelis
Fraunhofer Institute for Ceramic Technologies and Systems IKTS

Continuously operating mixing units, such as twin-screw extruders, gain ever-increasing interest in the battery cell production, as they can reduce production costs by decreasing process times compared to batch mixers. However, continuous quality monitoring of the battery suspensions or dispersions represents a challenge. Currently there are hardly any suitable inline testing technologies that do not influence the process. This abstract describes the development of a multiparameter inspection system that can measure the most important properties of battery suspensions and enables inline monitoring of the process.

The system is implemented at the outlet of an extruder and uses eddy-current and ultrasonic based techniques to monitor the dispersion quality. These two methods measure the electrical and acoustic impedance of the product. Due to the non-contact measuring a continuous monitoring without influencing the process is allowed. Additionally, no dilution of the dispersion is required to operate this inspection system.

In the context of test series with characteristic electrode materials (based on the active materials LiNi0,6Co0,2Mn0,2O2 (NCM622) und LiNi1/3Co1/3Mn1/3O2 (NCM111)) it was shown that a large number of parameters, such as the solid content, carbon black content and the particle size distribution have an influence on the paste viscosity. The challenge is to detect, which parameter leads to the viscosity change. With the presented multiparameter inspection system it is shown that a change in the carbon black content leads to a complex impedance change in the eddy-current signal. Furthermore, the addition of smaller particles (1µm) shows a shift of the frequency spectrum in the ultrasonic signal, which is caused by scattering effects. Additionally, increasing the solid content leads to larger damping coefficients and thus to smaller maximum amplitude values in the ultrasonic signal. Using this non-destructive multiparameter inspection system, the change in paste viscosity could be traced back to a specific parameter.

Recycling & Sustainability

Life cycle sustainability assessment of potential battery systems for short-range electric aircraft

Alexander Barke
TU Braunschweig | Institute of Automotive Management and Industrial Production (AIP)

The Flightpath 2050 strategy sets ambitious goals for the aviation industry to reduce the environmental impacts caused by air traffic. To achieve the envisaged emission reductions, new propulsion concepts for aircraft are under development. As already demonstrated for smaller aircraft with up to two passengers, electric propulsion systems can replace conventional jet engines on short-range flights and consequently reduce the in-flight emissions. However, the assessment of in-flight emissions merely addresses the diverse sustainability implications of novel propulsion systems. Especially, the batteries for electric aircraft are associated with several negative environmental and socio-economic impacts in the upstream stages of the life cycle. They consist of various critical raw materials, which are often extracted under poor working conditions and incur high processing costs. Furthermore, the production steps are energy-intensive and associated with harmful emissions.

This poster provides insights into the environmental and socio-economic sustainability of potential battery systems for electric aircraft with a particular focus on the raw material extraction and production stage. For this purpose, different battery systems with lithium-ion and lithium-sulfur cells are modeled and analyzed. Initial results of the life cycle sustainability assessment indicate that there are considerable differences between the battery technologies. With the higher specific energy and the lower share of critical raw materials, newer cell chemistries, such as lithium-sulfur, perform better than the current lithium-ion technology concerning almost all sustainability indicators. These results can mainly be explained by the different material and energy requirements for battery production.

Environmental Screening of Environmental Impacts of ASSB

Almut Kiesewetter
Fraunhofer Institute for Surface Engineering and Thin Films IST

All-Solid-State Batteries (ASSB) offer great potential regarding energy density and safety and are particularly attractive due to their fast charging properties. However, the upscaling of this technologies to an industrial level implies significant changes in current material production and cell manufacturing processes. Moreover, cell design and material properties in ASSB implies the possibility of incurring in environmental trade-offs when analyzed on a lifecycle perspective. The Life Cycle Assessment methodology offers in this regard a scientific basis to consider the interaction of technical systems and the environment while quantifying the effects. LCA-based tools offer in this regard the possibility integrate environmental knowledge within the development of new technologies. Nevertheless, most research on ASSB has been performed almost exclusively at the material development level on a laboratory scale and the manufacturing processes required have not been comprehensively researched hindering the development of full and comprehensive LCA studies. In this poster we aim at introducing the development and application of a screening framework to spot the potential environmental implications of ASSB on a lifecycle perspective. With this approach we aim not only at identifying potential unwanted consequences but also at prioritizing modeling and data collection efforts towards a full integrated life cycle engineering model. The screening approach is applied to compare three different battery cell technologies consisting of a polymer-based, ceramic-based and sulfide-based solid electrolyte.

Characterization of Li-Ion battery modules for second-life applications

Daniel Kehl
TU Braunschweig | Institute for High Voltage Technology and Electric Power Systems (elenia)

Due to the use of battery modules in the electromobility there will be lots of aged Li-ion based battery modules in the future. When the battery modules are reaching the end of the automotive product-life-cycle they cannot meet the automotive requirements sufficiently. The automotive requirements include inter alia the intrinsic safety of the energy storage system and a sufficient consistent capability to store energy (compared to new battery modules). This developement enables to build cost-efficient stationary energy storage systems when the battery modules are reused. To reduce maintenance work and to guarantee an intrinsic save operation of the system an initial check of the modules at the begin of second life is essential.
The incoming test has to provide informations about the state of health (SoH) of the modules and whether they are usuable for second life applications or not. By using the electrochemical impedance spectroscopy (eis) and the current interrupt (ci) method it is possible to calculate and analyze inner resistances and impedances at different operating points. A correlation analysis could prove that there is a correlation between the results of the electrochemical impedance spectroscopy method and the results of the current interrupt method. An implementation of the current interrupt method in a battery management system (bms) can be implemented cost efficient and thus allows to characterize the state of health of battery modules sufficiently for second life applications. Furthermore characteristic curves can be measured and recorded by varying the operating point. Modules with the same ageing history are tending to show the same characteric curves.

A view on battery production from the perspective of second life projects

Felipe Salinas
TU Berlin

Closing the gap between production and waste to transit towards a circular economy requires a strong coordination between manufacturers, (re)users and recyclers. In the context of Lithium-ion battery production, there is a growing interest in the reutilization of aged batteries removed from electric vehicles for stationary energy storages. However, the classification of this aged material for reuse depends heavily on characteristics related to the original state of the battery. Considering that more than 10 years may separate the moment of production and reutilization of a battery, relevant data may be lost like the chemical composition of the cell, or the expected performance under reference conditions. The need to study old cells as archeology subjects raises unnecessarily the cost of analysis, and thus, reduces the narrow chances of reutilization arising from the declining price of new batteries. On the other side, second life projects may provide relevant information to battery manufacturers about the lifetime of these products outside controlled environments, thus benefiting the former from joint efforts.
In this work we show difficulties observed during an attempt to reutilize a sample of aged cells manufactured between 2000 and 2015, which may be solved by a collaboration between producers and re-users.

Environmental and socio-economic sustainability assessment of an all-solid-state battery system

Jan Linus Popien
TU Braunschweig | Institute of Automotive Management and Industrial Production (AIP)

The European Union, as well as its industry and society, are facing major challenges to achieve the goal of being the first climate-neutral continent by 2050, as defined in the European Green Deal. A part of the solution for reducing climate-damaging emissions could be the use of battery-based propulsion systems in vehicles such as cars or aircraft so that the emission of CO2 or NOx while driving or flying could be avoided. New battery technologies, such as all-solid-state batteries, are under development since the currently available battery technologies cannot provide the desired ranges. However, the production of all-solid-state batteries is associated with environmentally harmful emissions due to the extraction and processing of raw materials and energy-intensive production steps. Furthermore, the extraction and production steps are often related to high processing costs and poor working conditions, which are aspects currently neglected in the assessment of all-solid-state batteries. Thus, this contribution aims to provide a better understanding of the environmental and socio-economic sustainability of all-solid-state batteries. For this purpose, an all-solid-state battery for the use in small electric aircraft is assessed regarding environmental and socio-economic sustainability indicators. The sustainability indicators are computed with a life cycle sustainability assessment model implemented in the Python-based Brightway2 framework. A comparison to current lithium-ion and lithium-sulfur batteries illustrates the advantages and disadvantages of all-solid-state batteries. The results indicate that the all-solid-state battery has lower impacts for almost all environmental and socio-economic indicators during the raw material extraction and production steps than the investigated lithium-ion battery. The examined lithium-sulfur battery, however, shows overall better results than the all-solid-state battery.

Life cycle assessment of metal and liquid-free organic lithium-ion batteries as sustainable and safe energy storage technologies

Merve Erakca
Karlsruhe Institute of Technology (KIT)

As a result of the energy and mobility transition, the demands of today's society on electrification and energy storage technologies are steadily increasing. One of the most promising technologies to meet these requirements are lithium-ion batteries (LIBs). However, new challenges are arising from these developments, such as shortcomings regarding sustainability issues. Besides the improvement of e.g. energy and power densities, there are also some safety concerns and relatively high costs related with LIBs. The reasons for these concerns are the low stability and high flammability of the liquid electrolyte and the use of critical and expensive metals such as nickel, cobalt or copper. MOLIBE, a German French project, addresses exactly these issues. The development of organic active materials, metal-free current collectors and non-metallic charge carriers will enable a new metal free battery technology. Moreover, the safety of the emerging battery will be improved by the implementation of polymer electrolyte systems. A crucial point in the development process is the implementation of a prospective life cycle analysis, in order to improve and to ensure the sustainability of the battery. Life cycle assessment (LCA) is used to evaluate potential environmental impacts over the entire life cycle of the new battery system. The LCA is carried out continuously from the beginning of the project to ensure the inclusion of sustainability aspects already in the early design phase.

Application of functional biopolymers for sustainable batteries

Raymond Leopold Heydorn
TU Braunschweig | Institute of biochemical engineering

The increased distribution of portable electronics and the current development of electric mobility have pushed the limits of lithium (Li)-ion technology regarding power density and safety. However, consisting of less sustainable materials and partly with highly reactive compounds, Li-ion batteries (LIB) do not yet meet the requirements of an environmentally friendly technology. The application of biopolymers allows for increasing the sustainability of LIBs along with other upcoming cell chemistries. Focusing on traditionally rather passive materials such as binders or separators, biopolymers can contribute to similar or even enhanced LIB performances due to the diversity of their functional groups and potential for customization which allows converting passive materials into active components of the battery.

Following the strategy of sustainable binders, biotechnologically produced γ-polyglutamic acid and xanthan were selected as natural binders and compared with polyvinylidene difluoride (PVdF) in graphite anodes. Further enzymatic and chemical treatment was conducted in order to tailor polymer chain length and enhance the electric conductivity for improved charge and discharge characteristics in Li-ion half-cells. For mimicking natural electron transfer, the aromatic amino acid phenylalanine was selected as natural conductor and coupled by carbodiimide crosslinking or Schiff base reaction to the respective biopolymer backbone. Rheology and results from gel permeation chromatography of the yielded polymers support the higher adhesion strength of manufactured electrodes for increasing molecular weight of the biopolymers. Cycling at 0.5 C for 100 cycles against Li counter electrodes and electrochemical impedance measurement revealed similar or improved capacity in comparison to PVdF but differing capacity retention depending on the biopolymer and its functionalization degree. Further investigations aim at balancing functionalization-derived improvement and electrode adhesion and to incorporate electroactive bacteria-derived electron transport mechanisms into LIBs for advanced and sustainable batteries.

Battery Production

VDMA Battery Production

The VDMA department is the direct contact for all questions relating machine- and plant construction. The member companies of the department supply machines, plants, machine components, tools and services for the entire process chain of battery production: From raw material preparation, electrode production and cell assembly to module and packaging production. The current focus of VDMA Battery Production is on Li-ion technology. Our activities:

- We research technology and market information: (Roadmap Battery Production Equipment 2030, Process Flyer Battery Production, business climate survey, short expert reports on employment effects)
- We organize customer events and roadshows (most recently in the USA, in China with CATL, BAK and BYD or in Korea with LG Chem and Samsung SDI but also with Automotive OEM etc.)
- We supervise fairs (Battery Japan, CIBF, Battery Show USA) and hold our own events, such as the VDMA Battery Production Annual Conference: Established itself as an important industry meeting
- We are in dialogue with research and science on current topics and on joint industrial research.
- We represent our industry in politics and the public.

If you have any questions, please do not hesitate to contact us!

Website: https://battprod.vdma.org/en/ueber-uns

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ProZell
Kompetenzcluster zur Batteriezellproduktion

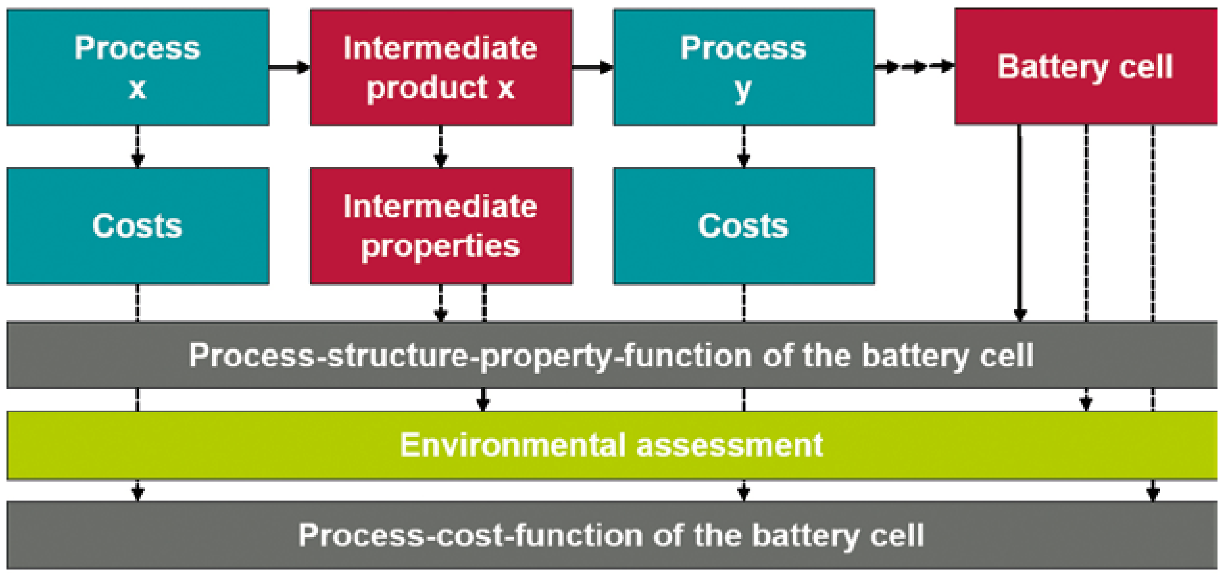
ProZell – Competence cluster for battery cell production – Influences of production steps and parameters on cell performance and quality – Challenges and goals

In the competence cluster for battery cell production (ProZell), German research institutions join forces to strengthen the national battery cell production. The aim of the competence cluster is to research and improve the entire process chain of the battery cell production and assess the influence of each individual production step on cell properties, product development costs and sustainability. The competence cluster elaborates the scientific basis for the establishment and sustainable development of an internationally leading, competitive battery cell production in Germany. In this context, the economic efficiency of cell production and the environmental assessment are highly relevant. While aiming at reducing the energy-related cell price (€/kWh), the competence cluster pursues the simultaneous goals of increasing cell performance, especially energy density, and elaborating recycling pathways for battery cells.

The central concept of the cluster is to cross-link specific knowledge, special equipment, and various research institutions in joint projects. In 15 research projects, experts and scientists from various fields of expertise collaborate on identifying variables that cause relevant changes in intermediate product properties, as well as cell performance, quality, and costs. Process-structure-property relationships and process-cost-functions along the entire process chain of the battery cell production are developed. An accompanying project fosters cooperation and networking within the entire cluster and ensures a structured bundling of knowledge in a results database. In addition, an advisory board including representatives from industry and research advises the projects and fosters synergies between research institutions and industry.

Contents and main areas of work

The continuous production of battery suspensions by extrusion, in addition to increasing the energy density through the targeted structuring of high-capacity electrodes and the use of silicon are areas of focus for the field of electrode production. A pre-lithiation technique adds lithium to the anode prior to cell assembly in order to increase the stability of lithium ion battery cells containing silicon during charging and discharging cycles. A novel dry-coating technology allowing for solvent-free electrode production diminishes the need for energy cost during expensive drying procedures and opens the door towards environmentally friendly electrodes. In addition, interactions between process control and product properties are investigated in detail, especially for calendering and post-drying of electrodes. Within the field of cell production, the optimization of filling and wetting processes, taking into account all essential cell components, is topic of intensive research. The energetic optimization of cell formation is investigated. The investigations regarding cell stack formation focus, above all, on the special requirements of high-energy electrodes. Overarching projects in the cluster focus on developing innovative quality assurance concepts to reduce fluctuations and rejection rates and to optimize the interlinked production processes with regard to an appropriate definition of production tolerances. Based on mathematical models for the entire process chain, the detailed understanding of related process-structure-property relationships is used in order to digitally describe the entire process chain and optimize it for new battery generations. Further points of interest are the comprehensive cost and environmental assessment of the process chain and the recycling of battery cells. A results database brings together key findings of the projects in a transparent manner.



Application, use of results and contribution to energy storage

The properties of electric vehicles and systems for the electrochemical storage of energy as well as their respective customer benefits correlate directly with the properties of the battery cells used. A better understanding of influencing variables along the entire process chain, including the production environment, is therefore essential. The establishment of an economical and sustainable battery cell production is the central milestone on the way to establishing Germany as a leading market and provider of electro-mobility. The fundamental challenge for competitive battery cell production is to increase cell performance while simultaneously reducing the energy-related cell price (in € per kWh). The knowledge gained in the competence cluster should form the essential basis for the development of economically producible battery cells, i.e. battery cells with a significantly improved performance-to-cost ratio. The results provide a scientific basis for achieving and continuously expanding the sustainable, international technology and cost leadership of all German industries involved in the value chain of cell production.

Partners and funding

Currently, the ProZell competence cluster comprises 15 partners, including the following universities and research institutions: TU Braunschweig, Karlsruhe Institute of Technology, Landshut University of Applied Sciences, TU Berlin, TU Clausthal, TU Dresden, TU Bergakademie Freiberg, Center for Solar Energy and Hydrogen Research Baden- Württemberg, German Aerospace Center via the Helmholtz Institute Ulm, Ulm University, RWTH Aachen University, TU Munich, Münster Electrochemical Energy Technology (MEET) at University of Münster, Fraunhofer-Gesellschaft, and Forschungszentrum Jülich via the Helmholtz Institute Münster.

The ProZell cluster was funded by the Federal Ministry of Education and Science (BMBF) with more than 16 million euros in the first funding period from 2016 to 2019. Due to the promising results and the good cooperation and collaboration within the ProZell competence cluster, the BMBF has been intensifying its financial support for battery research since 2019. The second funding period of ProZell started on October 1st, 2019 and comprises more than 35 million euros in total funding. The successful ProZell concept serves as a model for the establishment of further competence clusters by the BMBF, namely: InZePro – Intelligent battery cell production, greenBatt – Recycling/Green battery, BattNutzung – Battery use concepts, AQua – Analytic/Quality assurance.

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PRESENTATION ABSTRACTS

Electrode Production

Inline quality control for continuous electrode slurry production

Adrian Spillmann
Bühler AG

Continuous electrode slurry production is a prerequisite for large-scale manufacturing of LIB cells in order to significantly reduce investment and operation cost and at the same time, improve consistency and quality of the product.

Within the scope of this presentation, we will discuss the benefits of the fully continuous electrode slurry mixing process in combination with the inline quality control system QuaLiB™. The system allows a continuous traceability of the raw materials and a higher production yield due to a time-dependent traceability model and an automated quality control to minimize startup and shutdown losses.

Furthermore, we will elaborate on the inline measurement of the slurry viscosity and the implications on the subsequent coating process.

Effect of graphite anode morphology on the onset of lithium-plating in lithium-ion batteries

Alexander Adam
BMW Group

For electrified vehicles fast-charging is of high customer value. Ideally the required charging time for the battery is similar to refuelling a conventional vehicle with an internal combustion engine. Apart various challenges based on the periphery of batteries (e.g. available power of charging stations, battery pack cooling), the main leverage on cell level is the Li+-diffusion inside the porous anode structure with respect to fast-charging.

Diffusion limitations of the anode during charging with high currents lead to additional electrode polarization. Consequently the anode potential can drop below a critical value of 0 V vs. Li/Li+. In this case, the deposition of metallic lithium is favored over the Li+-intercalation into the graphite host structure. This deposition process is partly irreversible, resulting in a capacity loss of the lithium-ion cell and potentially causing safety issues. Therefore, it is necessary to reduce the effective diffusion path of the porous anode structure to overcome this limitation.

In this work the influence of the porous anode structure on the fast-charging capability of lithium-ion batteries is studied. Therefore, various analytical methods are employed to characterize the porous electrode structure of the anode, e.g. pore size distribution and tortuosity. Methods to detect Lithium-plating are applied to quantify the fast-charging capability. A correlation between the structural parameter(s) of the electrode and the determined charging limitations are used to obtain a deeper understanding of the influence of the electrode design on the fast-charging capability of lithium-ion batteries.

Advances in water-based electrode processing for high energy Li-ion battery manufacturing: Si-Gr/NMC622 cells

Iker Boyano
CIDETEC

Water processing of electrodes will reduce the cost in the production of advanced lithium ion batteries (LIB) and will lower the environmental impact of the electrode manufacturing step. While aqueous slurries for graphite anode manufacturing are state of the art, for oxide-based cathodes is still challenging to replace conventional NMP toxic organic solvent. Moreover, it is not always straightforward to upscale high-quality, reliable electrodes out of the most promising high-energy active materials. Indeed, the following main challenges have to be solved: (1) Processing high capacity silicon-containing anode to deliver electrodes capable to absorb heterogeneous particle size materials and volumetric changes over cycling; (2) High voltage cathode aqueous processing will require solutions for high pH-related issues and transition metal leaching from LiNi0.33Mn0.33Co0.33O2 (NMC111) and related Ni-rich layered oxides.

Selected results in these water-based electrodes production achieved at CIDETEC Pilot Plant will be presented: Graphite-Silicon blend anodes with up to 10 wt% Si nanoparticle content with irreversible capacity loss <15% on formation and reversible specific capacity of 600 mAh/g were developed within SPICY project. On the more challenging cathode side, the high pH and transition metal leaching issues have been studied in ongoing work within EU project IMAGE. Ni-rich layered oxide active material (LiNi0.6Mn0.2Co0.2O2, NMC622) has been processed with waterborne binders to achieve homogeneous loadings (3.0 mAh/cm2) and comparable performance (180 mAh/g-NMC) to conventional electrodes prepared from organic NMP-based slurries. Once optimized, they have been cycled in full coin cells showing promising performance. Overall, both the processability and the electrochemical performance of the materials have been successful, evidencing that water-based electrode manufacturing can lead to an upcoming generation of environmentally friendlier LIBs.

Customizing lithium-ion cells – From the first material tests to series production

Anne Baasner
Custom Cells Itzehoe

Through its high performance, the lithium-ion cell technology is dominating the energy storage market. In recent years, the lithium-ion cells have conquered many new applications such as automotive, marine, medical or aviation. At the same time, they are also often used for stationary applications such as storage, peak shaving or frequency regulation. Each application places different demands on the battery. Some applications require a longer life, other applications require high power or have a high energy demand. All requirements cannot meet by one battery setup and an adjustment of the battery cells is required to address each application with maximum efficiency.

During the presentation CUSTOMCELLS® concept to address the customizing of lithium-ion cells is shown. On the basis of flexible cell manufacturing process and state-of-the-art research and production facilities, CUSTOMCELLS® guarantees high-tech solutions for special applications and- depending on the customer requirement profile- tailor-made development and production of electrodes, electrolytes, battery cells and battery modules. At its sites in Itzehoe (Schleswig-Holstein- Germany) and Tübingen (Baden-Württemberg- Germany), CUSTOMCELLS®- Made in Germany- develops and produces application-specific battery cells from prototypes to small and medium series.

Beside the grate range of active materials, more than 14 different electrode are already industrialized, due to the high flexibility of pouch cells the cell format could be also customized. There are already a lot of different pouch cell formats between < 1 Ah to 100 Ah established. Recent developments at the cell development facilities like the increased coating capacities, an extruder slurry mixing process and automatic format-flexible stacker are presented. The CUSTOMCELLS® service portfolio also includes integrated consulting and services in the field of cell development and production. CUSTOMCELLS® assists you with all questions within the scope of technical consulting and prototyping of electrodes, cells and energy storage devices and supports you with technology Ramp-up from laboratory to production scale. More information on www.customcells.org.

Simulation based prediction of carbon black particle sizes in high intensity dispersion processes

Julian Mayer
TU Braunschweig | Institute for Particle Technolgy (iPAT)

Energy storage is a key technology for alternative power trains like electric and hybrid electric vehicles. Lithium-ion batteries (LIB) are widely used for this purpose due to their high energy density and elaborated developmental state. The increasing usage of electrified transportation leads to ever-increasing demands on LIBs in terms of fast charging ability and power density. The fragmentation of carbon black (CB) aggregates and agglomerates, respectively, has high impact on the resulting microstructure and mechanical integrity as well as conductivity of electrodes and furthermore, the electrochemical performance of LIBs [1]. To achieve optimized power densities and to reduce the process time and energy consumption, a method to predict carbon black particle sizes based on simulations and experiments has been developed.

The aim of the method is to achieve defined particle size distributions of the conductive additive CB with as little expenditure of time and energy as possible. The simulation based method enables a fast development of new formulations and materials with significantly reduced experimental effort, thus effectively increasing the economic efficiency in terms of product development. Additionally, the model is capable to scale smaller mixing devices to industrial scale energetically. To set-up the model, three experimental test series have been carried out in which for a planetary mixer the intensity of the dispersion process, the CB content and the dispersion time were varied. The basic slurry formulation has industrial relevance and contains > 95% active material and < 2% CB. Viscosity and CB particle sizes were measured during and after dispersion. The same processes were virtually carried out using Computational Fluid Dynamics (CFD) in order to obtain a quantitative statement about the shear rate and shear stress distribution in the mixing unit. The combination of the experimental and simulative results allows the creation of mixer type dependent and independent predictive models to forecast the size of conductive additive particles in high-intensity dispersion processes. By predicting the size distribution of the conductive CB particles, the model is also the basis for modelling the formation of the microstructure of the electrodes, as the particles have a significant influence on the formation of the CB-binder network during dispersion and drying. Further work will transfer the model to continuous suspension production in a twin-screw extruder.

The presentation shows selected experimental and simulative results of a high intensity dispersion process in a planetary mixer and based on these an approach to predict the carbon black dispersion process.

References:

[1] Mayer, J. , Almar, L., Asylbekov, E., Haselrieder, W., Kwade, A., Weber, A. and Nirschl, H., Influence of the Carbon Black Dispersing Process on the Microstructure and Performance of Li-ion Battery Cathodes, Energy Technol. (2019)

aNIR-Technology a game changer in electrode production?

Kai K. O. Bär
adphos Digital Printing GmbH

The advanced Near InfraRed (aNIR)-technology, is an electro-thermal systems technology, widely used for fast heating, drying, sintering and curing processes. The adphos developed technology consists of the combination of high energetic NIR-power sources with warm, high velocity impingement air ventilation. This process combination results in possible strong acceleration by drying and curing processes and has been now already successfully applied in multiple industrial printing-, painting- and coating lines, whether water based or solvent based inks/paints or coatings need to be processed. Beside reducing the process time, from minutes down to seconds (even sometimes sub seconds) and therefor tremendous resulting space reductions, the possible drying optimizations/adaptations achieve minimized energy consumption and enhance product quality. Comparing to fossil fired driers/ovens, even no direct CO2-emissions are given with the aNIR-technology. The aNIR-technology has been recently also successfully applied for thick film coating applications and is now also proven in drying processes required for electrode coatings and electrode production. Here a possible drying acceleration, compared to a conventional hot air tunnel of a factor 5 to 8 is demonstrated, either for the solvent based coatings and the water based electrode coatings. In this presentation, an introduction of the physical working principle of the aNIR-technology is given. In a competitive evaluation matrix, the special process and application benefits are outlined. Real application cases for electrode production are described and possible performance data presented. Resulting from the possible aNIR-based process configurations, new high improved productivity and enhanced coating quality can be achieved in a fraction of the todays necessary space of market offered process lines.

Continous extrusion of electrode materials

Nicole Neub
Coperion GmbH

The continous extrusion of electrode materials (anode and cathode masses) becomes more and more important in the cell manufacturing process. The optimized utilization of the rare and expensive raw materials is just one advantage shown by this process. Additional to this extreme short cleaning times, the self cleaning of the twin screw Extruder and Coperions experiences in dust proof handling of cancerogenix materials (e.g. NMC) are crucial and part of the presentation.

The lecture will talk about the specific customer benefits by changing the production process from discontinuous (Batch) to continous (Twin Screw Extruder). Despite that some of the actual developments in the area of solid state Batterie production via twin screw Extruder "ZSK" are touched.

Twin screw Extrusion is the most suitable process for the production of highly viscous compounds and with this benefit the leading Technology in the area of solid state batteries.

In case you need more Information in advance please just let me know. Looking forward to your Feedback !

Optimized High-Energy NCM622 Electrodes for Lithium-Ion Batteries Fabricated by Extrusion-Based Slot-Die Coating

Sebastian Reuber
Fraunhofer Institute for Ceramic Technologies and Systems IKTS

High-load electrodes are considered promising to improve the energy densities of Li-ion batteries (LIB) for mobile applications. Conventional casting processes for electrode coating are limited in terms of film stability and homogeneity, especially for thick, high-load electrodes above 4 mAh/cm². Furthermore, the electrochemical performance of such high-load electrodes is commonly insufficient, which results in prolonged charging times. To tackle these challenges, an innovative coating processes combined with a model-based design tool has been developed.

Based on analytical descriptions of the main rate-limiting processes in a LIB and a simple cell model, an application-oriented design tool is proposed (DLC-Tool). Due to its ease of use, it can directly be implemented into fabrication processes of Lithium-ion batteries. Decisive electrode parameters such as layer thickness, micro structure and composition are optimized regarding maximum energy density, while guaranteeing user specified boundary conditions, such as assembly space or rate performance limit. Herein, the DLC-Tool is applied to specify optimal design parameters of high-energy NCM622 cathodes that are then fabricated by state-of-the-art tape-casting and an innovative extrusion-based coating procedure. Accordingly, increased energy density on the cell level is achieved.

The developed extrusion-based coating processes includes a premixture of active materials, additives and binder solution that is well dispersed in a twin-screw extruder under high shear forces. The resulting pastes are extruded by a slot-die, laminated on a current collector foil and dried. By optimizing the geometry of the slot-die and the rheological properties of the pastes, a continuous coating process is established. The process enables the fabrication of electrodes with high active material loadings and coatings up to 7 mAh/cm², while avoiding the disadvantages of conventional casting processes, such as binder migration and adhesion problems for fast drying processes. Favorably high solid contents of up to 85 wt.-% can be are achieved and processed to NCM622 cathodes. Compared to conventional processing, the amount of solvent is reduced by 80 vol.-% and the corresponding drying time has been halved. Thereof the developed process exhibits substantial savings regarding materials and energy costs. The proper electrochemical functioning of the electrodes is successfully demonstrated by means of long-term cycle and rate capability tests of NCM622-graphite full cells.

Energy Efficient LIB Production

Silje Nornes Bryntesen, Ignat Tolstorebrov, Jacob Joseph Lamb, Odne Stokke Burheim
Norwegian University of Science and Technology (NTNU)

A sustainable shift from internal combustion engine (ICE) vehicles to electrical vehicles is essential to achieve a large reduction in emissions. Currently, the production of Li-ion batteries (LIBs) used in electrical vehicles is an energy-intensive and costly process that can lead to significant embedded emissions (depending on the source of energy used). In fact, 70-80 % of the energy consumption in LIB production is associated with drying processes, where the electrode drying accounts for about a half. Despite the large energy consumption and costs originating from drying processes, they are seldomly researched in the battery industry; however, there may be potential for adaptation of methodology and pathways from other industries. Establishing knowledge within the LIB industry regarding state-of-the-art electrode drying techniques and solvent evaporation mechanisms is vital for optimising process conditions, detecting alternative solvent systems, and ultimately discovering novel techniques. This overview aims to give an introductory summary of the industrial state-of-the-art LIB chemistries. An in-depth understanding of the influential factors for each manufacturing step of LIBs is established with emphasis on the electrode structure and electrochemical performance. Special attention is then dedicated to the convection-drying step in conventional water and NMP based electrode manufacturing. Next generation drying techniques are also reviewed, of which dry electrode manufacturing is considered the most promising. Solvent omission in dry electrodes substantially lowers the energy demand and allows for a thick, high-quality electrode coating. Finally, a critical aspect of the innovations and industrial modifications that aim to overcome main challenges are presented.

Preparation and functionalization of active materials with intensive mixers to increase the performance of electrodes

Stefan Gerl
Maschinenfabrik Gustav Eirich GmbH & Co KG

To further increase the specific performance of electrodes, the active materials are continuously optimized. While in the past, cathode materials in particular have been further developed, more and more research activities are now also being directed at anode materials. For example, silicon-doped or especially spherical graphites should enable a further performance leap in cell capacity.

In addition to the synthesis of active materials, however, functionalization through targeted modification of the particle surfaces by application of nanoparticles or solid or liquid functional layers is also becoming increasingly important. Although powder mixers are occasionally used in many of the known manufacturing processes, they are often only used for simple homogenization of the solids involved, but not or only very rarely for particle design beyond this.

The presentation will use a number of practical examples from the processing of anode and cathode raw materials to demonstrate the possible applications and performance of Eirich intensive mixers for the production of functionalised active materials. In addition to dry dispersing/mixing and, in some cases, kneading or granulating prior to active material synthesis, the mixers are used primarily for coating the synthesized active material, also as a combination process with superimposed tempering or drying. These one-pot processes can considerably simplify the production chain or significantly increase the efficiency of downstream thermal process steps. In addition to the optimization of bulk material properties such as bulk densities and powder flowability, the main goal is to achieve perfect material properties by, for example, an absolutely uniform surface structure of the active materials.

Some of the methods presented could also be integrated directly into electrode production for the manufacture of dry electrodes with Eirich intensive mixers or coating compounds with Eirich MixSolvers®. This opens up further possibilities for cell manufacturers to optimize cell properties by individually adapting the active materials available on the market.

Cell Assembly

Powering tomorrow with energy-efficient dehumidification systems and dry rooms

André Meyer
Munters GmbH

Lithium and other materials are highly reactive to moisture, so when using them as the basis for battery production, it is essential to operate in exactly the right dry environment. Lithium-ion technologies involve a variety of chemistries, but all variations benefit from precisely controlled climates including humidity control.

More important than anything else, you need a dry room to be able to meet the right dew point. Most manufacturers need the dry rooms to be maintained at a dew point of -40°C, and sometimes they will need it to be even lower. Munters pioneered the use of desiccant dehumidifier technology, and our innovative solutions are used in lithium battery production facilities all over the world. We have delivered many dry rooms capable of -60°C, and will continue to experiment with lower humidity levels.

To keep dry rooms at the right humidity and temperature can involve a significant amount of energy, but we make sure energy efficiency is central to all of our technology. Our patented Green PowerPurge™ makes a big difference, and you can benefit from annual energy savings of up to 45%. This reduction in energy requirements also contributes to the sustainability of your battery factory, and contributes to LEED certification.

Design parameters for a continuous stacking process in cell assembly of lithium-ion batteries

Christina von Boeselager[a,b], Klaus Dröder[a,b]
[a]TU Braunschweig | Battery LabFactory Braunschweig, [b]TU Braunschweig | Institute of Machine Tools and Production Technology (IWF)

The electrode-separator-assembly (ESA) comprises multiple layers of alternating electrode and separator sheets and represents the core of the lithium-ion battery (LIB). Three technologies are established for the production of the ESA: winding of continuous coil material, stacking of discrete sheets and z-folding where the electrodes are stacked as single sheets while the supply of the separator takes place from continuous coil material. Established stacking processes show various advantages regarding the handling of the sensitive electrodes, but involve time-consuming acceleration and braking movements of pick-and-place operations. These processes show hardly any potential for further enhancement of the stacking speed. New stacking processes need to do without discontinuous pick-and-place operations to overcome this disadvantage of single sheet stacking. A new approach for a high speed stacking process is the use of a continuously rotating paddle wheel. In this process, two feeding units insert electrodes into the wheel. The paddles transport the electrodes subsequently in a rotational movement and finally discard the electrodes onto a stack. This technology is established for currency discrimination and counting but needs to be adapted for electrode stacking. This presentation shows the assessment of materials and design parameters for the paddle wheel with respect to the requirements of the assembly of electrodes. Based on simulations and experiments, the translational movements of the electrodes on the paddles are analyzed, which cause frictional forces and thus damage the coating of the electrodes. Finally, a suitable set of parameters for the blades is discussed, which minimizes the influence on the sensitive electrodes.

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Mono cell inspection in the battery cell production - How to increase and ensure the position accuracy of the electrodes in-line in the lamination and stacking production process?

Klaus Hamacher
BST eltromat International GmbH

In the lamination and stacking process step of the production of pouch cells, maximum precision in web guidance is an elementary requirement. Here, two webs of electrode (anode and cathode) and two separator webs- total of four- are controlled with networked web-guiding controls in such a way that they can be precisely positioned, cut and stacked with one another. Here, too, the master / slave and offset correction functions make it possible to regulate the web edges in such a way that the webs are guided to one another with the required position accuracy. This is possible thanks to a new cell inspection system especially for this requirement, which transfers all relevant contrast, object and layer information to the multi-web-guiding control system (close loop control).

Filling and Formation of large Li-ion-cells – where scaling up is non-linear

Stefan Roessler
Zentrum für Sonnenenergie und Wasserstoffforschung Baden-Württemberg (ZSW)

Since established in 2014, the Research Production Line (FPL) at ZSW Ulm provides close-to-production conditions for LIBs in PHEV-1 format in order to support the transfer of laboratory-research results to mass-production. High standards are set regarding quality, automation as well as reproducibility and continuously optimized during the large amount of conducted orders for cell production on the FPL over the last years.

Increasing energy density inside the cell and making bigger cells have been two major trends during the past years. While the influence of cell volume to capacity is easily understood, the effects of different cell designs and sizes on the required production infrastructure on the other hand, is often harder to grasp.

In this presentation, an insight in the cell activation process will be given for 25Ah PHEV1-cells beginning at electrolyte filling and ranging over formation. These processes are currently the most time-consuming process in the process chain of electrode and cell production and amount for a significant portion of the capex for a Li-ion-cell production. Due to the high degree of automation in the production line the influence of deviating inputs, that is found in laboratory scale research can be kept as small as possible and effects of the processes on the cell performance can be identified clearly.

Building the pan-European battery ecosystem

Stefan Wolf
VDI/VDE Innovation + Technik GmbH

The proposed European Green Deal paves the way to enhance investments in green technologies as well as the development of sustainable solutions and new businesses. Batteries are an important enabling factor in achieving a climate neutral Europe by 2050. The European Strategic Action Plan on Batteries accounts for the importance of this technology field and creates the political framework conditions. To implement this plan the European Commission started an initiative to set up two Important Projects of Common European Interest (IPCEI) on Batteries. These projects create a framework to scale up the European battery technology ecosystem through intens cooperation of European companies compliant with world trade rules. The core activities of these IPCEIs will be research and innovation of current state-of-the-art battery technologies, focussing on LIBs. Additionally, the demonstration of next generation battery cells (e.g. ASSB, Li/S, NIB) and battery related technologies will be promoted to prepare their mass market introduction. The focus of IPCEI activities will lay on battery cell production while also covering up- and down-stream stages of the battery value chain. Another important goal of the IPCEIs is the development of solutions for sustainable battery production comprising recycling, carbon neutral production and fair working conditions along the value chain. So far, more than 70 companies from 12 EU member states have committed to contribute to the IPCEIs with more than 100 enterprises within its ecosystem. These companies cover all steps of the battery technology value chain within Europe.

The contribution gives an overview on the status quo of the IPCEIs to put them in context of the European battery market and political framework conditions. Innovation needs for the establichment of a functioning and competitive European battery manufacturing eco system will be shown. Furthermore the contribution will provide information on how the IPCEIs build upon existing strctures and take advantages of market developments. Thus, a deep understanding of the European battery ecosystem and the role of the IPCEIs shall be conveyed.

Evaluation of flexible cell assembly processes and novel, flexible production equipment

Tobias Storz
Karlsruhe Institute of Technology (KIT) | wbk Institute of Production Science

Despite the wide range of applications and requirements, standardized cells are used for a lot of products. Standardized cells can’t fit all the different needs of the various battery driven products. Our hypothesis states that product manufacturers will demand batteries adapted to their requirements for electric properties and installation space. This will result in a growing variety of battery cells regarding dimensions, format and materials. This trend is already visible in batteries for consumer electronics like smartwatches and smartphones.

To keep up with varying customer requirements, cell manufacturers will need suitable, flexible machinery to avoid large reconfiguration costs for every new type of cell.

As a solution, an agile type of cell production equipment will be developed at KIT. In a first step towards agile production, wbk is in the process of developing and building a robot cell for pouch cell assembly that covers the production steps stacking, contacting and sealing. It will feature a production modules to carry out the before mentioned processes, a simulated micro-environment and a robot for handling the cell (stack). Being part of the ongoing project “SmartBatteryMaker”, two material systems (NMC622/ graphite and LFP/ graphite) and two different cell formats (rectangular and trapezoidal) will be able to be processed in the robot cell without the change of tools.

To achieve “plug & work” properties in the production modules, a service-oriented machine control will be adopted.

After giving a detailed description of the “SmartBatteryMaker” equipment and processes, a first evaluation regarding productivity, process capabilities and quality will be given. Finally, the novel production equipment will be rated via comparison with state of the art production lines to show potential improvements to be made in future adaptations of the agile production concept for battery cell manufacturing.

Sustainable and automated Li-ion cell production

Ulrike Polnick
Industrie-Partner IP PowerSystems GmbH

The development of processes and the design of appropriate machines as efficient and ecologically beneficial solutions is a major issue for an eco-friendly production of lithium-ion battery cells. Find out how IP PowerSystems solves current problems in conventional processes by developing a novel and patented technology for electrolyte filling without dry room.

The innovative technology offers great potential for saving energy, costs and reducing the carbon footprint, especially for mass production. The process enables faster electrolyte filling and wetting. Furthermore, there is no need for a vacuum chamber for filling. This leads to the fact, that a pressure gradient is emerged between the evacuated cell interior and outer standard atmosphere enhancing faster wetting. In addition, unnecessary disposal of contaminated waste is avoided by eliminating the gas bag. In this way IP PowerSystems contributes to a more sustainable battery production, not only in terms of material and cost efficiency but also in energy efficiency.

Further enhancement in efficiency and automation of battery production can be achieved with the Robo Automation Kit. This flexible automation system is module-based and allows the easy integration of existing machines in production lines for pouch, prismatic and cylindrical cells. Due to combination and recombination of various modules a more flexible and efficient production can be established.

Battery Production 4.0

Analyzing and tailoring quality control measures for managing product variance in battery cell production lines.

Anna Sophia Kollenda, Gunther Reinhart

Technical University Munich| Institute for Machine Tools and Industrial Management (iwb)

To meet the customers' requirements for high cell capacity and high power, battery cells are continuously improved, leading to variants that differ e.g. in cell chemistry or cell format. The product variants, characterized by different product properties, induce changes in the production steps. When changing from hardcase to pouch cells, e.g. tabs instead of terminals must be welded or sealing of the pouch foil instead of welding the hardcase lid is necessary (PETTINGER ET AL. 2018). To ensure the required cell quality, the inspection processes have to be qualified for the corresponding altered process and product properties to be checked, respectively. As activities for quality assurance generate additional cost (PFEIFER & SCHMITT 2014), the implementation is restricted. They should be applied precisely and to a minimum extent to allow for profitable production. Thus, detailed knowledge about the consequences of variance on the quality assurance measures is necessary to decide which adjustments have to be made to manage quality in the face of variance.

This contribution aims to summarize the latest research on the influence of product variance on quality assurance measures and methods for managing these. As baseline, a review about management methods suitable for managing variants is presented together with a comparative analysis of quality measures applied in two research production lines. Furthermore, a method is introduced which supports the analysis of production lines regarding the influence of a specific product change on the quality measures. It also includes the classification of the variant under consideration, a tool for identifying necessary inspection technologies, and offers support in a subsequent economic evaluation of these measures.

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Industry 4.0 Software Architecture for Battery Cell Manufacturing

Bob Zollo

Keysight Technologies

The cell formation and grading section of the cell manufacturing line is the largest, most expensive, and most costly to operate portion of the cell manufacturing line. Today, some cell manufacturing lines are relying on 20 year old technology because it is safe and reliable. But advances in factory automation, cell forming electronics, measurements, data collection, and control systems offer the promise of improved productivity and efficiency, better flexibility and agility, and increased profitability. With the increased availability of process data and big data machine learning, it is further possible to feedback real-time insight and adapt the process on the fly to give the highest quality cell output.

We will begin by outlining the top characteristics that are desired from the software that controls the cell formation line. While this presentation is focused on cell manufacturing, these concepts also scale down to R&D/prototype lines as well.

We will describe a system architecture, comprised of software and machine elements, based on Industry 4.0 technologies, to implement each of those desired characteristics.

We will cover what technical and financial benefits, such as improved productivity, increased operating efficiency, and strengthened system security, can be derived from operating a system using Industry 4.0 technologies in the architecture we describe. Technologies including cloud-based control, cloud-based data storage, and edge computing will be covered and their pro's and con's described.

Lastly, we will cover how this architecture provides easy and secure access to process data, making possible the use of big data analysis / machine learning. The output of this machine learning makes it possible to feedback real-time insight and adapt the process on the fly to give the highest quality cell output.

On-Line Solutions to Optimize Electrode Coating Uniformity in Battery Production Processes

Gareth Joseph

NDC Technologies

Since the start of mass production of secondary battery cells, the default measurement technology for the coating process lines has been the Beta (Krypton 85) sensor technology. While this technology has the capability of measuring the coating weight of electrode materials, higher measurement capabilities are needed for today's exacting performance energy storage devices.

This webinar reviews the latest developments in measurement technology that provides manufacturers with greater visibility (and control) of their coating lines. This insight helps Lithium Ion Battery cell manufacturers to understand the dynamics of the coating process, enabling the production of cells with better and more consistent anode and cathode coating uniformity. The presentation also addresses the benefits of higher spatial resolution measurement, higher speed of measurement and reproducibility of measurement as it pertains to coating uniformity.

Towards smart electrode manufacturing: challenges and possibilities for in-line quality control in electrode production

Marcel Dittmer

TU Braunschweig | Institute for Particle Technolgy (iPAT)

Production and material costs are a huge factor in electrode production. Especially the uprising demand for materials and the limited amount of raw materials, efficient production processes and the reduction of waste is key in order to keep the costs in check. While most of the cell assembly processes can already be automated, the electrode production lives from empirical, determined process parameters and product characteristics. Characterization methods are almost exclusively offline without any relation to the production devices. Since most processes are based on empirical values quality gates, that define whether the sub product is processed further or not, are non-existent so far.

In context of smart manufacturing a continuous product monitoring is key for databased approaches and the implementation of cyber-physical systems in electrode production. Especially in continuous slurry production in-line sensors can be used to develop control concepts that ensure constant product quality and prevent materials from further processing that do not fulfill predefined quality gates.

This work provides an overview on the current challenges and possibilities for intelligent manufacturing processes in electrode production. This includes the introduction of quality gates as well as the implementation of continuous in-line product monitoring across all sub-products. Despite the general concept, the findings for different in-line capable sensors will be highlighted as well as general process-product correlation that are necessary for the further development towards an intelligent process chain. In this regard the color measurement will be introduced as an in-line product monitoring in continuous extrusion and coating process.

Module & Pack Production

Matrix Production Lines – Production Power for the World of Tomorrow

Alexander Weis
SCIO Technology GmbH

A key challenge of electric mobility is meeting the demand for battery packs and modules. As the scale of demand rapidly increases in the coming years, battery producers must adjust their production lines and capabilities. SCIO Technology has developed a scalable platform technology which enables fully-automated module production. The flexible production lines can quickly be fitted to produce a variety of different battery module and/or pack sizes so that the production never stands still. The flexible end-of-line testing assures consistent high quality results. In my presentation, I will describe how such a matrix production system is set-up, how a matrix production system differentiates itself from standard production lines and why this is the solution to meeting current and upcoming industry needs. Production power for the world of tomorrow.

Alexander Weis is CEO and founder of SCIO Technology GmbH. He is a trained electrician and has a Master of Mechanical Engineering from the RWTH in Aachen. During his studies in Aachen, he was a member of the "ecurieaix" young entrepreneurship team which developed and presented the first fully electric race-car. In addition, he worked as a student worker in the prototyping department of Streetscooter focusing on the electrical components, the high-volt switches and the fusebox. This led to his participation in the AC2 business plan competition in which he and his team achieved a top 10 placement out of more than 140 participants. Following his studies, he was a member of the e.GO founding team and joined e.GO as operative employee Nr. 1. After 5 years at e.GO, he took the leap into entrepreneurship and founded SCIO Technology in 2017. SCIO Technology develops and manufactures customer-specific battery systems in series. The patented manufacturing process enables efficient production to meet tomorrow's energy needs. Alex lives and breathes e-mobility.

Production of Future-Proof Automotive Battery Systems

Thomas Decker
Webasto SE, Energy & Components, Battery Systems

Webasto decided to go into the automotive battery system business
Webasto was founded in 1901 and is still a family-owned company. Meanwhile, Webasto is a global leading automotive supplier for roof systems, convertible systems and heating solution.
In order to grow, Webasto needs additional business. A business where we could make use of our core competencies.
Our main knowledge is the understanding of the automotive OEM's needs and the integration of own systems into their cars.
We have the expertise in mechanical integration of our products into a given space and to integrate our systems into the electronic car infrastructure. With our heating systems, we have a dedicated expertise in thermo management. Moreover, we know how to produce on a high quality level and to realize a highly efficient production on a global base. All these competencies are key for building automotive battery systems, charging solution and high voltage heaters.
In 2016 Websto introduced E-Solutions & Services (Battery Systems) and Charging Solutions to the market.
In 2017 we won a first series order for a battery system from a well-known European bus manufacturer and we introduced the global product launch of the Webasto CV Standard Battery System for commercial vehicles at the IAA in Hannover.
The Production Line Challenge
Winning orders and introducing products means to care about their production. As we start with relatively low numbers of batteries, we looked for an efficient and flexible solution. Our line consists of fully automated stations where it is required, combined with flexible manual working stations where it is possible.

In parallel, the line must be able to produce two very different products. The products differ in size, weight, modules, voltage level, working content, BOL and EOL requirement.

In addition to this, the line needs to be very compact because it has to fit into the restricted space in our existing roof plant.

The challenge was to create a line design that combines all product specific requirements, the general requirements like technical cleanness, HV safety and of course feasible robust processes with a great variety of parts and space restrictions.

The next step was to start our standard Webasto approach by using so-called 3P workshops. Within these workshops, several interdisciplinary teams create different solutions.

After distributing the work content into single stations, the teams had the task to create several technical concepts. Afterwards, the teams simulated there solutions by building up the stations out of cardboard, wood, palettes etc.

To have the single battery parts as realistic as possible, we created "prototypes" out of wood, cardboard and 3D printed plastics.

After the evaluation of the different solutions, we connected the chosen stations to a 1:1 size line model. On this way, we elaborate the rough line concept.

Together with an experienced line supplier, we started to develop station by station. Having the first 3D data, we used different CAD systems for the next steps. We took the data of the single stations to create 2D layouts. In parallel, we used a digital factory tool for the 3D layout.

The result is a flexible and expandable multi-product AGV line. This line can produce two different types of batteries.

We integrated an innovative line feeding system by using the AGV's to store most of the single parts we assembly in the line.

In a first step, our line supplier installed a basic version of the line in their facilities. To produce the first samples packs and to check the chained line, we organized an intermediate production of several weeks.

After this first production run, we moved the line to our plant. Since mid of 2019 the line is installed in our Schierling plant. Currently we rump up the production of the two products.

Design considers, safety lessons and new developments of lithium-ion batteries for industrial applications

Dr. John De Roche
aentron GmbH

The presentation will elaborate the design considerations for lithium-ion batteries when utilised within an industrial environment. Consequently will be discussed the impact of design on both active and redundant safety. Finally, a review of new generation battery technology where current safety relevant risk have could be reduced or eliminated.

Laser Meets Battery Cells

Sören Hollatz
Fraunhofer Institute for Laser Technology ILT

The growth of the electric vehicle industry is generating a high demand for efficient energy storage systems. These systems, consisting mostly of Li-Ion battery cells, are one of the most criticized aspects when producing an electric vehicle. Performance, cost and energy efficiency in battery production require further research.

As a well-established tool for efficient material processing, the laser beam has high potential to improve the battery performance in multiple steps of battery production. Starting with the drying of the active material, the laser enables electrode drying on the shortest possible timescale and minimal space requirement in the production line due to the precise and intense application of energy. Removing the active material for electrode structuring or cutting of the electrode foils are further applications for the laser beam. Finally welding processes can be performed, such as welding of electrode foils, prismatic cell housings or battery connectors for module manufacturing.

In order to address these different processes from the perspective of laser technology, the Fraunhofer Institute for Laser Technology is setting up its own laboratory with machines specially adapted to battery applications. The presented work will give an insight into the laboratory, the laser processes and further investigations.

Leak testing of battery packs during pack production

Thomas Odenthal
INFICON GmbH

Proper quality control during battery pack production and assembly is key to long term performance of battery packs in the field. Battery packs should not leak cooling liquid in order to avoid loss of cooling capacity and electric shortages. At the same time, no water ingress into the battery pack should occur to also avoid electric damage. Battery packs are often classified as IP67 or IP69K for this purpose.

Battery trays and battery packs need to be tested for leakage during production and as part of end-of-line testing. The presentation will show testing results to determine to what leak size battery packs and cooling circuits need to be tested- to avoid the above failures. In a second step, best practices in how to perform the required leak testing during quality control will be discussed.

Production of Solid State Batteries

Processing of Sulfide Solid Electrolytes for All Solid State Battery electrodes

Henry Auer
Fraunhofer Institute for Ceramic Technologies and Systems IKTS

All-solid-state batteries (ASSB) exhibit significant benefits in gravimetric and volumetric energy density, operating temperature range, and safety in comparison to conventional liquid electrolyte based systems. While fundamental research at the level of materials has made considerable progress in recent years, the scalable production of components and cells for ASSB has hardly been addressed so far.

The present work focusses on the processing of sulfide solid electrolytes. This class of material exhibits high ionic conductivities > 1 mS/cm and allows processing at room temperature. At IKTS a scalable processing of sulfide electrolytes as solid electrolyte separator (SES) and ion conducting phase in composite electrodes (anode, cathode) is investigated. For the manufacturing of slurry based SES, the sulfide electrolyte is first dispersed in a binder solution and then casted using a doctor blade. To prepare composite electrodes, the sulfide electrolyte, the active material and an optional electron conducting phase are dispersed in a binder solution. These slurries are directly coated on current collector foils. The microstructure, homogeneity and electrochemical properties of the composite electrodes and the SES are analyzed and compared to pristine, cold-plastically compressed reference materials. The processing conditions have been varied to achieve high ionic conductivities for the slurry based manufacturing, while exhibiting significantly higher scalability potential when compared to the cold-plastic reference process.

Based on these developments, advanced sulfide-based composite electrodes are prepared with blended active materials that exhibit a protective coating. Following systematic studies on the impact of design, composition and reactivity against the sulfide electrolyte, blends with favorable processability , improved energy and power density and enhanced cycling performance are designed, serving as input specifications for the electrode processing.

Processing of All Solid State Batteries: Recent Advances

Ingo Bardenhagen
Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM

All- solid-state batteries (ASSBs) are considered the next step in battery technology. Advanced features of ASSBs over the state-of-the-art Li-ion batteries (such as enhanced intrinsic battery safety and increased energy density) are of particular interest. Especially the potential use of alternative electrode materials, such as metallic Li as an anode material and cobalt-free high-voltage spinels as cathode materials, are of interest [1]. Currently, a vast number of ASSB related research focuses on the investigation of suitable ceramic [2], glassy [3] and polymer-based [4] solid-state electrolyte materials as alternatives for the liquid electrolyte.

In the next step, the processing of these solid-state electrolytes needs to be addressed. One possibility is adapting processes already used for components in conventional lithium-ion cells, such as slurry preparation and coating. In this case, the slurry processing has to be done with at least one more (solid) component therby increasing complexity of the process to achieve a homogeneous film. An additional challenge arises from the reactivity of the solid electrolyte with humidity forcing the manufacturing process to be carried out in dry conditions (a dry room or glovebox). In addition, especially in the case of polymer electrolytes, new processing and shaping techniques, such as extrusion, open new ways of producing lithium-ion cells.

In this presentation, we will give an overview over the current activities at the Fraunhofer IFAM for the production of ASSBs including sulfide and polymer-based cells. Here, we focus on evaluating the promises of the ASSBs which are heavily dependent on the manufacturability of homogenous and thin components.

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The potential of thin film technologies in the production of ASSB

Nikolas Dilger
Fraunhofer Institute for Surface Engineering and Thin Films IST

All-Solid-State-Batteries (ASSB) have gained in importance for energy storage systems, because of their high energy density as well as higher safety combined with low cost. To achieve sustainable components with optimized interfacial properties and improved long-term stability, coating technologies to apply thin films such as Physical Vapour Deposition (PVD) or Chemical Vapour Deposition (CVD) offer high potential.

For cathodes the electrochemical stability of active material particles can be enhanced with coatings of inorganic protection layers by an Atomic Layer Deposition (ALD) process. In the field of solid electrolytes an innovative hybrid approach is taken to directly apply organic, inorganic and hybrid materials on a cathode as a solid-state separator utilizing an advanced Atmospheric Pressure Plasma Process.

Furthermore, the sputter deposition process has been identified for a cost- and resource-efficient production of anodes. First results of a deposited lithium-metal-anode with thicknesses under 20 µm indicate improved electrochemical properties while saving material volume compared to conventional lithium-metal-anodes based on foils (thickness > 100 µm). The scope of our research is now the identification of process parameters to apply anodes with optimized compositional and structural properties by collecting process and material data by off-line and process-integrated characterization methods. Understanding process-product-relations can significantly facilitate the development of resource- and performance-optimized battery production technologies.

Structural and electrochemical characterization of polymer-based all-solid-state cathodes manufactured by a scalable process chain

Laura Helmers, Linus Froböse, Peter Michalowski, Arno Kwade
TU Braunschweig | Institute for Particle Technolgy (iPAT)

All-solid-state batteries offer great potential as next-generation batteries as they enable the use of a lithium metal anode. This technology offers the potential to improve fast charging properties, the achievable energy density as well as safety [1]. In the development of solid polymer electrolytes the main drawback is the low ionic conductivity at room temperature and the limited electrochemical stability window [2]. Through the manufacturing process the transport structure and interfaces within the electrode can be influenced [3]. It is still a topic of current research to build polymer-based all-solid-state cathodes by scalable processes and achieve the requested transport properties.

Therefore, a solvent-free scalable process was developed for manufacturing of polyethylene oxide based all-solid-state cathodes. Starting with a granulation step to mix the different components, adjust the carbon black agglomerate size as well as the density of the granules. By a following extrusion step a dense compound is formed. The influence of screw design and process parameters like mass flow on the residual porosity and the transport properties of the extrudates are investigated. Through a calendering step the cathode is compressed to the targeted layer thickness. The calendering force and temperature are varied and the effect on structural changes is associated with different input polyethylene oxide chain lengths. The increase in polymer chain length shows an improved dispersion behavior of the carbon black particles leading to enhanced electrical transport properties. Finally, the electrochemical performance of the manufactured cells is analyzed. The effect of applied pressure during cycling on reduced internal resistance is characterized. The all-solid-state pouch cells reach a discharge capacity of 60 to 85 mAh at 1C and 80 °C.

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Influence of the dispersing method on the performance of Lithium Solid-State batteries

Maica Morant-Miñana
CIC energiGUNE

Solid-state batteries employ solid electrolytes and electrodes to obtain safer batteries with higher energy densities. A common solid state battery configuration employs a polymeric electrolyte, a metal anode and a composite cathode. In addition to the conductive additive and the active material, the composite cathode contains a solid electrolyte to assure the ionic pathways within the electrode. For a fixed composition, the composite electrode microstructure and morphology play a significant role in the performance of the solid state battery. These parameters are strongly dependent on the mixing sequence, employed mixing devices and the operating conditions such as mixing time and speed.

Several mixing devices have been explored in the literature to achieve well-mixed slurries and their flow behavior must be well characterized and understood to prepare coatings with uniform thickness and homogeneous component distribution. In this work we will present the effect of the mixing method employed for the cathode preparation on the final battery performance. Experimental characterization will be performed to investigate the possible mechanism of this effect. On the basis of this development a successful method to prepare solid state batteries using Li anode and polymer electrolyte will be described.

Electrode, Cell and Module Diagnostics during Production

Electrochemical Impedance Spectroscopy (EIS) for battery cells, module and packs

Albert Gröbmeyer
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Electrochemical Impedance Spectroscopy (EIS) is a valuable measurement method to gain insight into battery cells, module and packs for e-Mobility applications. In this presentation, we will

- Review the benefits of applying EIS at all stages of battery storage: materials, cells, modules, and packs
- Compare EIS to ACIR (AC internal resistance measurement)
- Highlight the critical requirements for cell/battery EIS: Measurement of impedance levels as low as tens of µOhms over a broad frequency range from mHz – 30 kHz.
- Describe unique and advanced technologies that Keysight has created to improve EIS measurements: Precise low noise measurement hardware, fixture designs suitable for wide band frequency measurement, calibration and error correction.
- Show how EIS output data is used as input data to modeling algorithms to extract the equivalent electrical circuit parameters of the cell.
- Discuss EIS measurements and how they relate to State of Health (SoH) and second life applications.
- Provide a preview of future technologies under development to improve EIS for practical measurements at all stages in the battery storage life cycle: materials, cells, modules, and packs

An analytical method for the quantification of magnetic particle contaminants in powder materials for lithium-ion batteries

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Purity is a key requirement in a number of applications and the lithium-ion industry is setting stringent requirements to reduce internal faults and increase safety standards. Trace elements in a powder material can be present in different states, and their effect on the application can therefore be different according to the status. Trace elements can be present in the material as dissolved impurity or as particle contamination. It is well established in the lithium-ion industry that such particle contaminants play a major role in cell safety performance, however their reliable quantification is still an open discussion and there is not an established and generally accepted analytical method for the quantification of such particle contaminations.

In this study we focused on the quantification of magnetic contaminant particles, specifically Fe, Cr and Ni contaminants. The possible effect of the test sample size on the measurement performance was investigated a priori by calculation. Particle contaminants are randomly distributed inside the material and might have different sizes. Large contaminants are likely to be less common. Calculations were done to assess possible test sample effects on precision and bias. It is demonstrated that small test samples strongly affect the precision, and might introduce significant bias. Based on such calculations the optimal test sample size was defined as 500g.

Experimental clean working conditions are a key aspect to quantify ultra-trace particle contaminants and distinguish them from total bulk trace elements and external contaminants. We developed a method based on wet extraction of magnetic contaminants using a coated SmCo magnet. Magnetic particles, namely Fe, Cr, Ni based, are collected from the test material and concentrated onto the magnet surface. The extracted contaminants which stick on the magnet coated surface are then digested in aqua regia, and finally quantified via ICP-MS.

Using a large test sample and controlled process we validated an analytical method to quantify trace iron and magnetic based contaminants in the powder materials used in battery applications. As demonstrated, three different test powders and blanks were tested ten times providing reliable results ranging over 3 orders of magnitude, i.e. from 10 to 10'000 ppb of Fe. Level of detection and quantitation, as well as precision and accuracy are discussed.

Classification and risk assessment of lithium-ion battery cells by parameter-based methods

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Battery modules consist of individual battery cells, which are electrically connected to each other in series and/or parallel during module assembly. A classification of battery cells prior to their utilization phase in the module group is absolutely necessary, since qualitatively different cells can affect the performance and aging behavior of the entire module. In a parallel connection, balancing currents occur from good to bad cells, which accelerate the aging of the cells. At the same time, the overall performance of cells connected in series is only as good as the worst cell. As a result, unclassified cells can lead to faulty production in module manufacturing and cause additional costs. While the evaluation of the cells in an in-house production line is referred to as an end-of-line test. In the case of commercial battery cells this is referred to as an incoming goods inspection. Fast and cost-efficient test designs with a high degree of significance have top priority in the design of test routines for the classification of purchased cells.

In the scope of the investigations shown in this work, two differently designed incoming goods inspections were carried out on 300 commercial lithium-ion battery cells from KoKam (CNom = 5 Ah) with the aim of deriving recommendations for optimal test procedures for cell classification. A short quality test which lasts only 3 hours is compared to a long quality test which has a test period of nearly 3 days. The short quality test consists of electrochemical impedance spectroscopy, a high current discharge pulse and a 1C-5C full cycle. The long quality test mainly consists of recovery cycles at 1C, quasi-open circuit voltage curves with C/10, C-rate tests at C/2, 3C and 5C as well as SoC dependent internal resistance tests and electrochemical impedance spectroscopy. The parameters that can be derived from the two test strategies are statistically evaluated, key figures are identified and the cells are classified according the results. The classification is linked to data from the long-term cyclization in order to evaluate the significance of the key figures.

In the following highly reproducible mechanical safety tests were carried out at these cells under variation of the state of charge (SoC) and health (SoH) [1]. On the one hand, it could be guaranteed that all cells meet the same quality characteristics before testing. On the other hand, the influence of SOC and SOH on the characteristic reactions of the thermal runaway could be determined. In order to describe the processes taking place the cell voltage, resulting temperatures on the cell surface and infrared-active gaseous reaction products were determined and compared with time resolution. With the help of this investigation, allows an assessment of risks and consequences from events that occur during the use phase of a battery cell.

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Evaluation of an In-Line particle characterization method for Battery-Materials and -slurries

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Batteries keep both essentials and comfort of modern life running with safety and reliability. They have a long list of real-world applications – consumer electronics power, Electric Vehicle, solar power storage, UPS, alarm systems in remote locations, mobility equipment and portable power packs. Design, modeling and simulation of mills, extruders, .. is currently based on experience and measurements from the laboratory or with the help of laboratory analysis devices. In particular, the highly concentrated product flows in battery production are difficult to measure quickly and reliably. One thing is already perfectly clear: the processes throughout battery manufacturing operation need to be optimized in order to achieve target properties and sustain quality.

Towards smart manufacturing in electrode production the implementation of quality gates and establishment of continuous product monitoring is key. Currently the particle size analysis in electrode production is almost exclusively realized through laser diffraction. Due to the high solid content and the presence of different materials in battery slurries, a sample preparation process prior to the measurement is mandatory and therefore in-line measurement requires a lot of effort. A quantitative size measurement of the particles in terms of size, shape or color in real time, directly in the process, can and should make process optimization and control possible. In this regard optical microscopy is a promising alternative that can be used for in-line particle characterization in dry and wet processes.

For this purpose, an in-situ photo-optical analysis method with high spatial and temporal resolution was developed, which has already been tested for reliability in various studies. To evaluate the technology in detail, not only the application in different battery slurries will be shown, but also physical and technological limits of the technology will be discussed in detail. This discussion contains the analysis of the influence of concentration and viscosity of the slurry, set-up of the photo-optical device as well as the influence on the measurement of different slurry materials in general. All results achieved inline will be compared with laser diffraction results to show the comparability of the inline results to existing knowledge.

Cell Finishing

Formation - a critical production step for cell quality?

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The lithium ion battery (LIB) cell price, besides falling from several hundred US$ to around 100 US$, is still considered a major challenge for the breakthrough of electro-mobility. Besides the material cost another significant cost driver is the cell production process with the formation process as a major contributor.

Common LIB electrolytes are thermodynamically unstable at the present anode potentials, hence, decomposition occurs. The formation process is governed by the electrochemical decomposition of the electrolyte, which leads to the formation of a protective layer, the so called solid electrolyte interphase (SEI). At the cathode side, the so called cathode electrolyte interphase (CEI) is starting to form immediately by contact with the electrolyte predominantly due to chemical reactions on the cathode surface. The SEI and CEI are further modified by the so called "crosstalk" between anode and cathode. Both layers are capable of reducing further decomposition reactions between the electrolyte and the electrode surfaces to a minimum, thus guaranteeing good cell performance.

In literature formation procedures using different currents, constant voltage steps, cut-off voltages, and number of cycles are reported, leading to formation times of several hours to several days.

In this work, we provide a detailed study investigating the thermodynamics and kinetics of the formation process realizing formation times lower than two hours. The results were validated for different cell chemistries based on different anodes, cathodes, and electrolytes, as well as different cell designs, utilizing different balancing, porosity, and mass loading.

Learning 1: Solid electrolyte and cathode electrolyte interphase formation show extremely fast formation kinetics with regard to former state of knowledge, allowing a fast formation with a formation time lower than two hours.

Learning 2: Aging, described in literature as a quality enhancing procedure after the formation process, did not show a significant influence on cell performance at all. Hence, aging is only used to determine self-discharge properties.

Learning 3: The new insights into the formation process allows for a significant decrease in cell production cost.

Prospects of using predictive quality during cell finishing to reduce the process time

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The production of lithium-ion batteries (LIBs) has a high energy and resource consumption and therefore shows a high potential for improvements and cost savings. High scrap rates of 5-12% increase the overall production costs and decrease the throughput [1]. As LIB costs are mainly driven by material expenses (70-80% of total costs), production rejects have a massive impact on the overall charges [2]. This is particularly relevant concerning the later process steps, which start with the electrolyte filling and are summarized as cell finishing. Before the aging process, about 95% of the value-added has already been achieved, but it takes up to three weeks for the last 5% during aging before the LIB is subjected to the End-of-Line test [2]. Hence, high-quality controls are required to prevent defective cells from blocking cycler capacities.

Recently, much effort has been spent on developing approaches from the fields of machine learning and artificial intelligence to create lifetime prediction models for LIBs. These models were successfully validated for industrial produced cylindrical cells and could also be applied within the production line for large-format LIBs [3]. However, expensive potentiostats were used which would increase the already high investment costs (~30% of total investment) in comparison to simpler cell cycling devices [2].

This contribution highlights the demands as well as the challenges for predicting cell quality without depending on data from additional potentiostats during aging. First, relevant measurement parameters (e.g. impedance, voltage profile) from the process steps “wetting” and “formation” are analyzed to develop a quality gate before the aging process. Subsequently, requirements for production systems on pilot-scale are derived and time reduction is evaluated. Initial findings show that the use of impedance data originating from the wetting step in combination with voltage profiles obtained during formation can reduce the process time of the aging step to less than three days while maintaining steady quality.

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Sustainability

Towards sustainable supply chains for batteries: Insights from a spatially differentiated assessment of environmental and social impacts

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With the growing demand for sustainable batteries, the environmental and social impacts related to their production are increasingly scrutinized. This is an intricate task due to the complexity of the global supply chains and the regional differences of technology, environment, markets and society. Moreover, the impacts can be influenced by managerial supply chain design decisions, such as sourcing strategies or production locations. To better understand the sustainability implications of supply chain design, quantitative approaches for a spatially differentiated sustainability assessment of batteries are developed in the research group “Sustainable Supply Chains & Factory Systems” at the BatteryLab Factory Braunschweig. The objective of this presentation is to give an overview of the assessment results for selected battery systems and to discuss how supply chain design decisions affect environmental and social sustainability. To this end, alternative supply chain configurations are compared and the contributions from different materials and production processes are analyzed. It is shown that modifications in sourcing strategies for raw materials and locations for battery cell production can change the environmental impact scores (e.g., climate change, acidification, eutrophication) by up to 30% in both directions compared to a reference supply chain based on the current production mix. For social indicators (e.g., risk of corruption, risk of child labor), the variations are even higher. These results open promising research opportunities to advance the design of sustainable supply chains.

CO2 optimized battery manufacturing in Europe with upstream integration potentials

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P3 automotive GmbH

For the success of electric vehicles in the market, reduced CO2 emissions are essential for broad customer acceptance. Thus, low CO2 emissions during production are going to be a key competitive advantage for European car manufacturers. The component with the highest CO2 impact during production of the electric powertrain is the battery. The presentation will give an overview of the CO2 emissions for the value chain of a European battery production site (reference setup).The Focus will be on the CO2-footprint of the battery cell production process as well as on upstream integration of key battery cell materials. The comparison of CO2-footprint and production costs will indicate strategical approaches to achieve a CO2-neutral yet economically feasible battery production in Europe.

LCA of different battery cell technologies taking uncertainty corridors into account

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A central lever to decarbonize the transport sector from a life cycle perspective are electrified vehicles due to their better GHG performance compared to Internal Combustion Engine vehicles. Although the battery is a major contributor to GHG emissions of BEV, reported GHG emission values of battery production differ significantly from study to study. Reasons are the lack of reliable industrial data, uncertainties in cell chemistry, differences of production sites and intransparencies in battery supply chains. The uncertainties of these input parameters are hardly addressed in current literature although it is an integral part of LCA studies.

Initially, in this work a deterministic LCA for three different battery baseline models (NCM111, NCM622, NCM811) was conducted based on collected primary data from representative suppliers. Afterwards, an uncertainty method developed in this work was used. For this purpose, uncertainty distributions for input parameters were considered, and potential correlation was taken into account. The 95% interval of every product system was obtained through a Monte Carlo Simulation with 10,000 iterations and a global sensitivity analysis was conducted.

The results of deterministic Baseline LCA Models reveal that NCM111 has the highest environmental burdens in all examined categories. Taking uncertainties and bandwidth into account, the discernibility analysis indicates that in 89% of the cases NCM622 has lower GHG emissions than NCM811. The global sensitivity analysis indicates that natural graphite and electricity demand in cell production have the greatest influence on overall system uncertainty.

The study shows that considering uncertainty corridors are required especially when evaluating future technologies. Further research and more primary data for battery materials is needed in order to reduce uncertainty

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