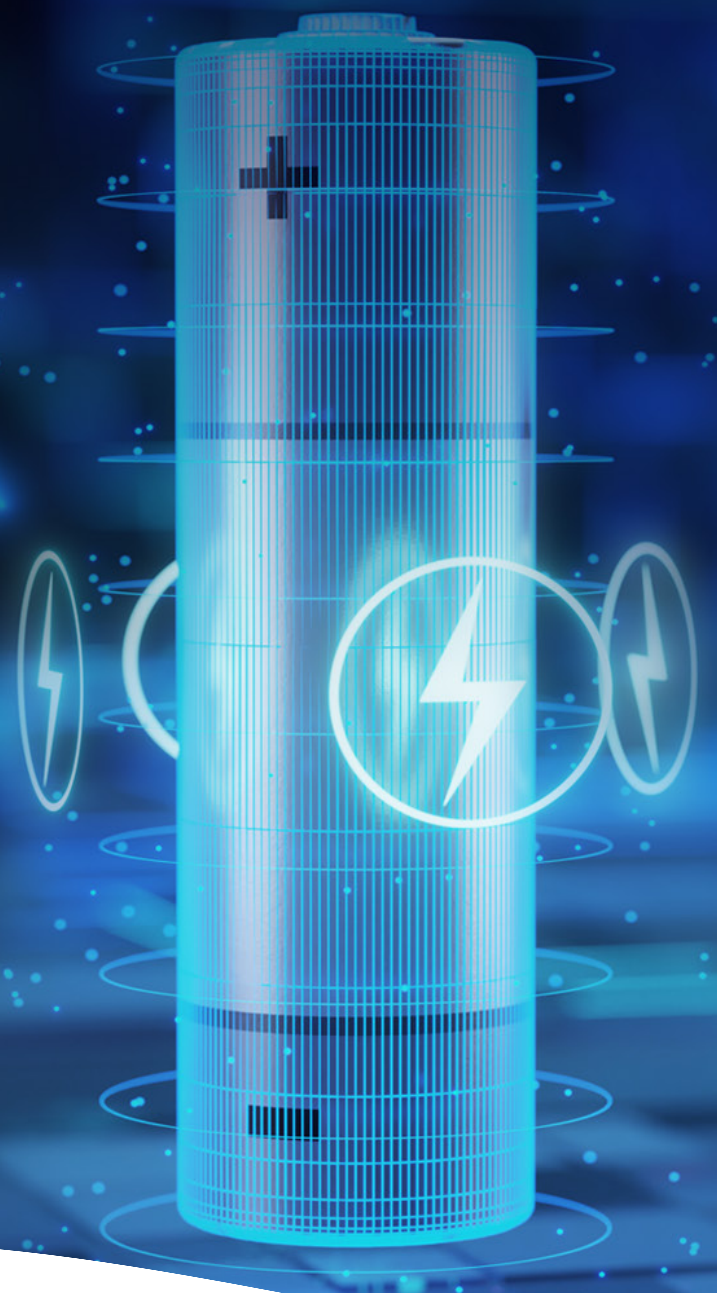
Battery Testing and Materials Characterization

A Selection Guide for Analytical Solutions



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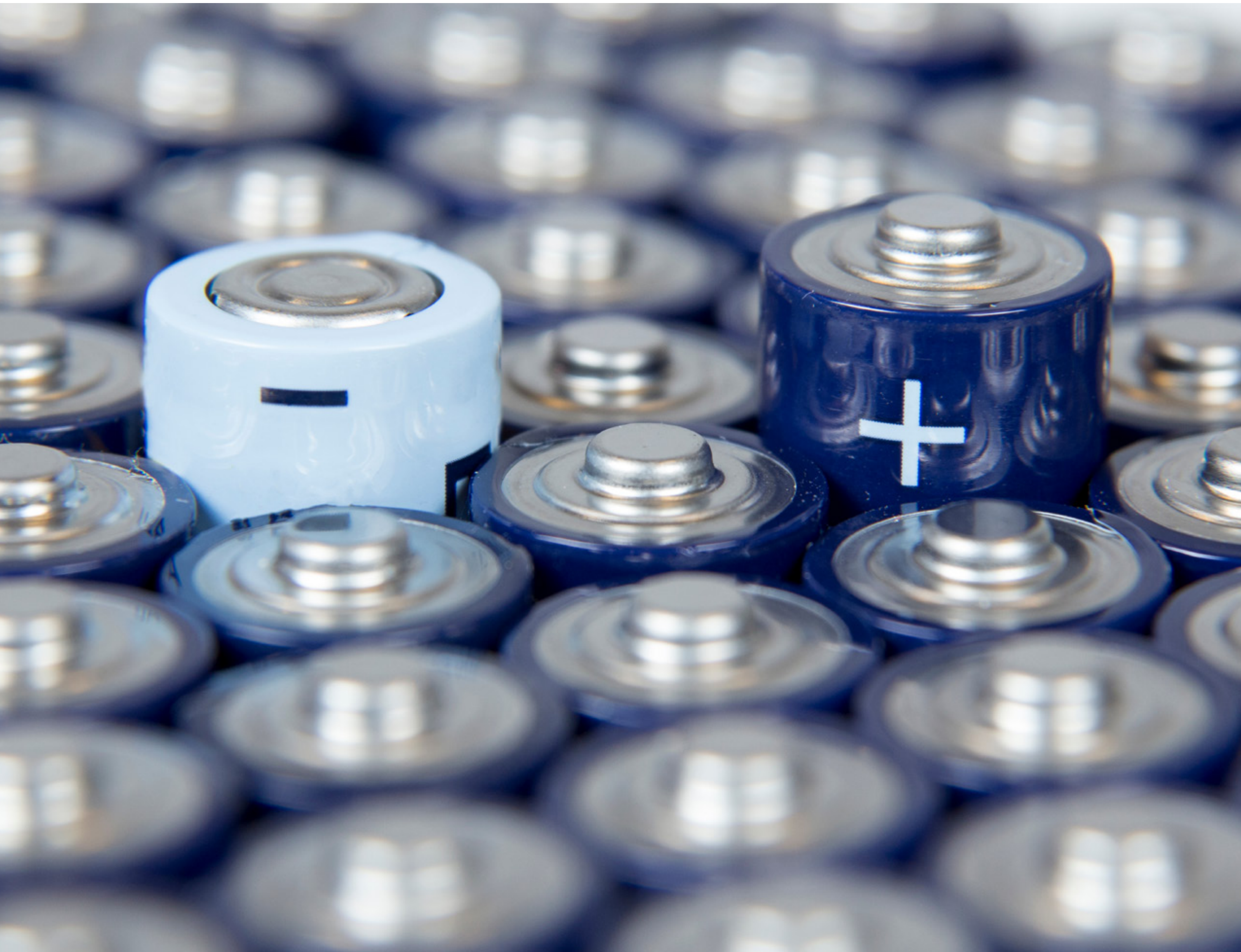


Unlocking the Full Potential of Batteries

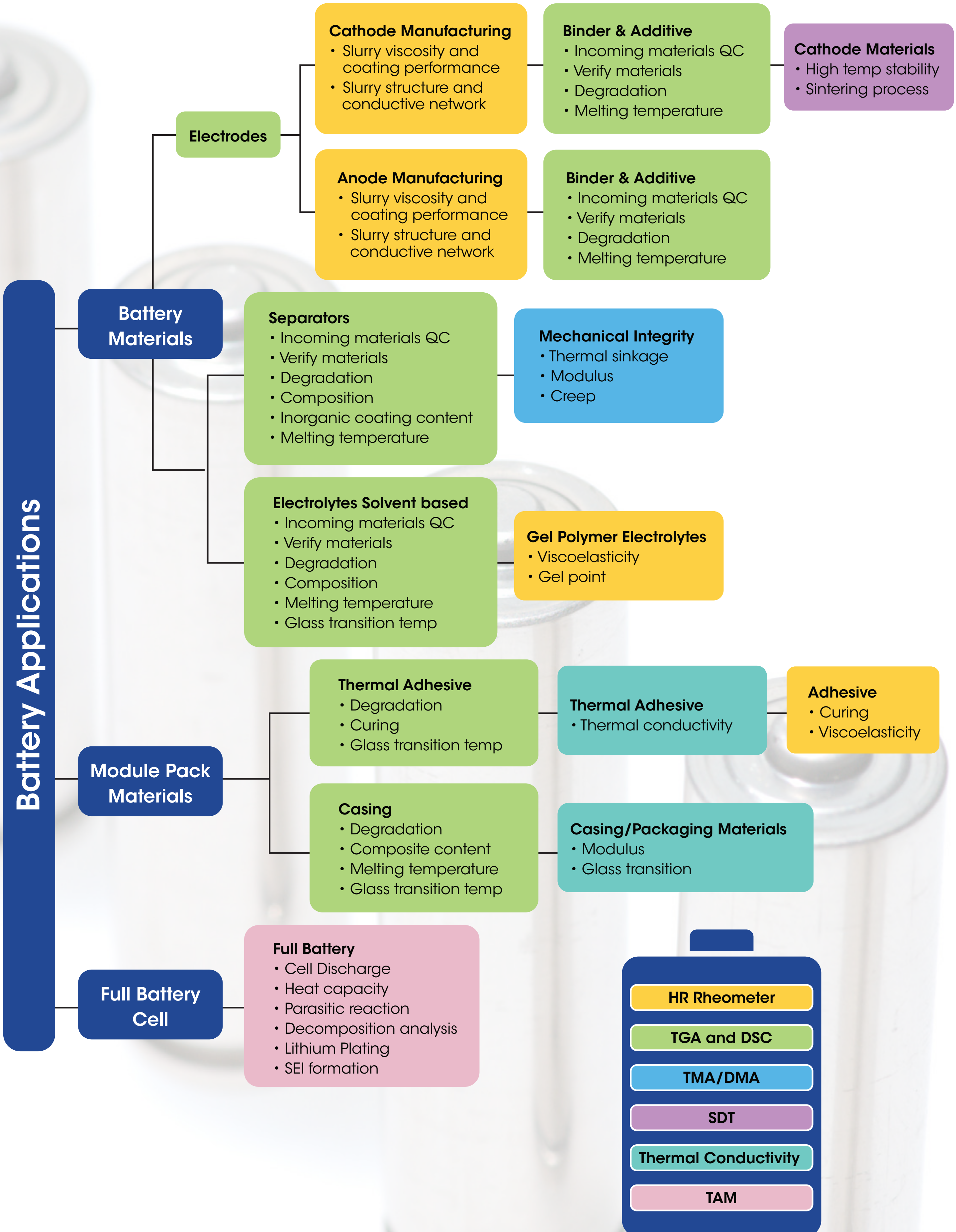
Cutting-Edge Analytical Solutions for the Next Generation of Battery Development

The race for the next generation of battery technology is well underway. In just a few decades, rechargeable batteries have grown well beyond their roots in consumer electronics and now support sustainable transportation and renewable energy storage. Tremendous advancements in battery efficiency, power, output, and safety have primed batteries, especially lithium-ion batteries, for these demanding applications.

Now, battery developers are tasked with optimizing their designs for both current and new applications. In addition to building safer, low-cost electric vehicles, batteries must reach even higher energy density for use in freight trucks and buses. Similarly, batteries with higher capacity and lower costs will be the formulations of choice for grid energy storage. And above all else, battery developers must meet demand for sustainable, affordable material sourcing in the face of lithium and cobalt scarcity.

The frontier for battery innovation is vast but the challenges are steep. Success will be determined by small margins in energy, power output, cycle life, safety, and cost – all of which require superior optimization of battery materials and electrochemical reactions. Leading labs rely on TA Instruments for analytical characterization and testing of their batteries.

Using the right techniques and instruments gives you the upper hand in efficiently advancing battery technology with proven quality and performance. From R&D and material selection to manufacturing and quality control, TA Instruments' solutions support the full breadth of battery innovation. This guide explains our comprehensive battery offerings by battery component, so you can find the right technique to enhance your battery development.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Binder & Additive
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Full Battery
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TGA and DSC
TMA/DMA
SDT
Thermal Conductivity
TAM

Full Battery Cell

Testing battery cells is an important step in optimizing battery chemistries and evaluating changes before scaling designs to larger formats. Battery scientists need to determine cells' efficiency as well as degradation during cycling. When isothermal microcalorimetry (IMC) is paired with a cycler or potentiostat, critical insights on lifetime predictions, cell performance rankings, and heat management evaluation can be developed.

Numerous notable battery labs, including the Jeff Dahn group and 3M, have published research using TA Instruments isothermal microcalorimeters paired with battery cyclers for full cell testing. The new Battery Cycler Microcalorimeter Solution is built with this application in mind. The solution pairs TA Instruments' state-of-the-art TAM IV Microcalorimeter to measure the thermal behavior of samples with the BioLogic VSP-300 Potentiostat, a research-grade electrochemical analysis tool to probe the electrical properties of materials. The result is an end-to-end, in-operando measurement tool for elucidating the thermodynamic and electrochemical details of battery cells in real time, in a flexible and intuitive system with pre-programmed methods.

BioLogic

Method	Description
Heat Management (CCCV)	Measures heat flow during cycling, primarily used for thermal management applications. This method will program different charging profiles (variable charge / discharge rates) using constant current constant voltage (CCCV) parameters.
Entropy Changes	This method consists of a slow cycle (C/20) followed by a very slow cycle (C/100) for maximum resolution into the structural and phase changes that occur during lithiation/delithiation.
First Cycle Reaction (SEI formation)	Method designed to study the SEI formation reactions. This method applies a small charging current in the low voltage range where SEI formation occurs (typically below 3.0 V), then applies a higher charging current until the standard upper voltage limit is reached (typically 4.2 V).
Full Cycle Parasitics	Method to measure the parasitic power over the full voltage range. The term "parasitics" is a blanket term for any non-reversible side reaction that contributes to battery degradation.
Narrow Cycle Parasitics	Method to measure the parasitic power in a narrow voltage. This is a faster technique if only one (or more) narrow voltage windows are of interest.
Self-Discharge	Experiment for measuring the self-discharge rate. This combines the conventional technique (monitoring open circuit voltage over time, then discharging to measure the remaining capacity) and the thermal method of integrating the total heat produced over the open circuit time.
Manual	Custom experiments, programmed by selecting actions, wait times, and event markers in the run sequence menu.

Battery Cycling Resources

Application Note: Determination of Parasitic Power in Lithium-ion Batteries using the Battery Cycler Microcalorimeter Solution

Application Note: An Overview of Isothermal Microcalorimetry in Battery R&D and QA - TA Instruments

Learn more about the Battery Cycler Microcalorimeter Solution.

Battery Materials

Electrodes

Electrodes connect battery terminals to the electrolyte and house the chemical reactions for charging and discharging. Electrodes therefore must demonstrate good electrochemical stability with the electrolyte as well as hold large amounts of ions without changing their structure. Cathode materials have been at the forefront of battery innovation in recent years, with anode materials now gaining attention as the next area of development.

Electrode Manufacturing

All batteries require cathode and anode coatings on a current collector. Modern industrial battery manufacturing uses slot-die coating, in which the electrode slurry is deposited onto the current collector to form a smooth, uniform coating. In order to speed up battery manufacturing, researchers are optimizing slurry formulations and testing different drying temperatures.

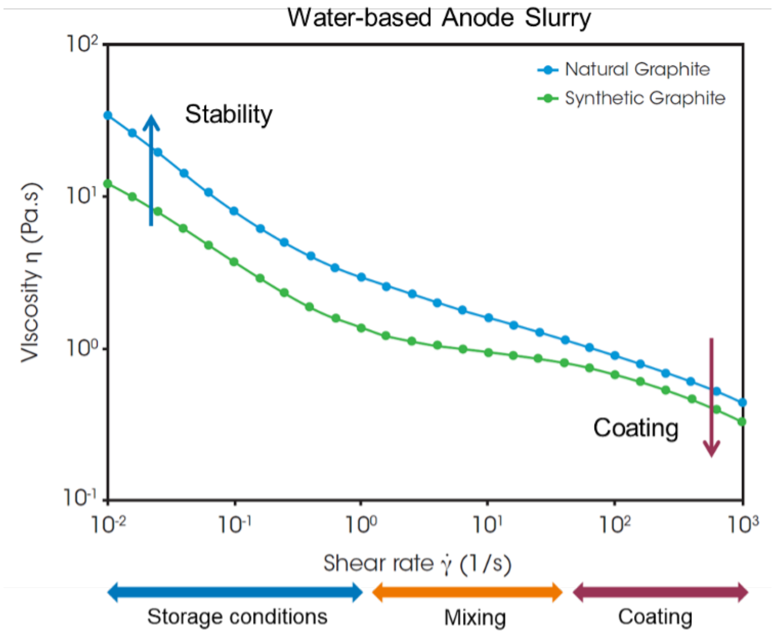
Rheology enables engineers to produce consistent slurry viscosities that result in uniform coatings for high performing and safer batteries. A rheological profile measurement can help ensure a uniform, defect-free coating that leads to production of consistent, high-quality electrodes with high batch-to-batch repeatability and low scrap rates. Engineering new slurry materials, formulations, or processing methods all require thorough rheological characterization to verify the slurry's quality.

Using accurate, reliable rheometers gives labs the upper hand in predicting slurry behavior before application, saving valuable resources and time. Screening incoming raw materials or new formulations helps users detect unexpected behavior and avoid large-scale production issues. While viscometers measure basic viscosity and flow, rheometers add shear or stress measurements that provide crucial information on slurry structure and behavior.

What to Measure	Technique	What it Means	Why it Matters	TA Instrument
Viscosity	Rheology	The stability and shear-rate dependent flow behavior of a slurry	Optimize coating speed and electrode quality	Discovery HR
Viscoelasticity	Rheology	Whether the slurry is liquid-like or gel-like at different frequencies	Identify slurry network structure	Discovery HR
Yield Stress	Rheology	Minimum stress required to initiate a flow	Determine shelf life and stability against sedimentation or phase separation	Discovery HR
Drying Time	TGA	Measure the coating drying time and kinetics	Choose the most cost-effective drying process	Discovery TGA
Thixotropy and Thixotropic Recovery	Rheology	A time-dependent shear thinning phenomenon	Determine slurry structure change during coating and recovery of the structure	Discovery HR
Impedance under Shear Flow	Rheo-Impedance	Shear-dependent conductive network and structure change	Ensure optimal conductive network under the relevant processing conditions	Discovery HR Rheo-Impedance Spectroscopy

The ideal slurry has a low viscosity for optimum mixing and coating (high shear rates), but a high enough viscosity for good levelling during drying and for minimizing particle settling and agglomeration during storage (low shear rates).

Since slurries are made up of solid particles of active materials, conductive additive, polymeric binder, and solvent, battery labs benefit from rheometers capable of testing all materials separately as well as combined in a slurry. The Discovery Hybrid Rheometer is uniquely capable of switching between solid, liquid, and powder samples in less than 10 seconds with industry-leading results and intuitive operation.



Advanced Peltier Plate

Peltier Concentric Cylinder

Powder Rheology

Rheo-Impedance Spectroscopy

Slurry Rheology Resource

Application Note:

Rheological Evaluation of Battery Slurries with Different Graphite Particle Size and Shape

Shear and Flow Properties of an NMC Based Dry Cathode Powder

Characterization of LIB Cathode Slurries Using Simultaneous Measurements of Rheology and Impedance Spectroscopy

eBook: Essential Battery Slurry Characterization Techniques

Binder and Additive

In addition to ensuring proper electrode coating, the binder and additive in electrode slurries greatly contribute to the overall performance. Binders require high thermal stability, good adhesion, and flexibility to facilitate proper battery performance. Low quality binders and additives can cause cracking and chipping on the electrode coating.

Battery developers typically test binder and additive at two key stages:

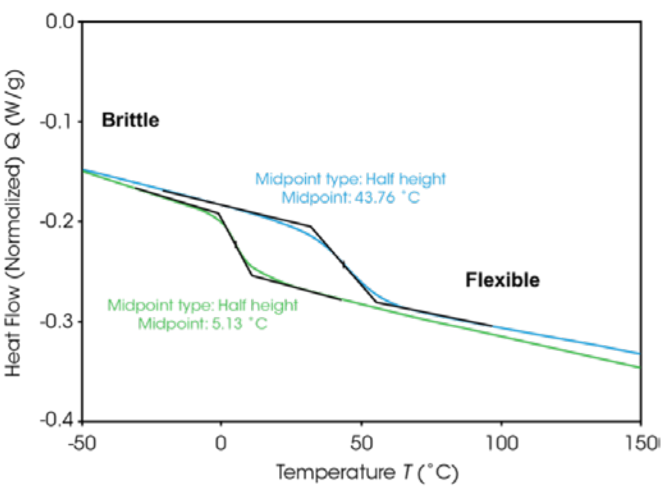
- To verify incoming materials' quality
- To measure the binder and additive's composition and electrode performance

Thermogravimetric Analysis (TGA) measures weight change (loss or gain) and the rate of weight change as a function of temperature, time, and atmosphere. Loss of mass indicates possible decomposition or vaporization, while a gain in mass indicates possible oxidation, sorption or that the material is reacting with the purge gas.

In batteries, TGA quantifies the amount of binder and additive in the electrode. This measurement helps ensure the same amount of active material, binder and additive are in each batch of electrode. On the Discovery TGA, the high sensitivity Tru-Mass Balance is ideal for binder and additive testing as it ensures accurate measurement of each component in the electrode. Insufficient amounts of binder will affect the active the electrode material's adhesion to the metal collector; too much binder will reduce the active material's content and affect the electrochemical reaction. Optimization of binder/additive ratios is essential for optimal battery performance and improvement of battery life.

TGA also measures the thermal stability, degradation temperatures, and content and composition of binder and additive. Thermal stability can help identify the right composition and types of the binder to ensure proper performance during electrode manufacturing.

Differential Scanning Calorimetry (DSC) measures binder melting and crystallization as well as glass transition. Crystallinity is related to a binder's mechanical properties, so this measurement can be used as a diagnostic to predict binder behavior. Glass transitions are related to the binder's flexibility, and DSC also reveals melting of the binder which will impact the thermomechanical properties. Lithium-ion batteries typically operate at temperatures of -20 °C to 60 °C. Higher temperatures can disrupt the solid-electrolyte interface (SEI), or even lead to decomposition. Thermal analysis enables researchers to understand the thermal stability of the electrode while optimizing slurry composition and solvent drying for improved batteries.



Characterization for Binders and Additives

What to Measure	Technique	What it Means	Why it Matters	TA Instrument
Decomposition temperature	TGA	Thermal stability of the binders	• Thermal stability of binder • Ensure incoming materials quality	Discovery TGA
Weight change	TGA	Composition of binder and additive	Ensure correct composition	Discovery TGA
Glass transition	DSC	Brittle glassy state to a flexible rubbery state	Impact on the binder properties	Discovery DSC
Melting and Crystallization	DSC	Phase transition on the polymer properties	• Ensure incoming materials quality • Process optimization	Discovery DSC

Active Cathode and Anode Materials

A battery's cathode, or positive electrode, is usually made of a metal oxide; the anode, or negative electrode is usually made of graphite. The cathode and anode are capable of intercalating lithium ions during charge and discharge. The electrode must hold lithium ions without changing its structure, offer good electrochemical stability with the electrolyte, and be a good electrical conductor and diffuser of lithium ions. Additionally, the thermal stability and rate capability of the entire battery is largely dependent on the cathode and anode material.

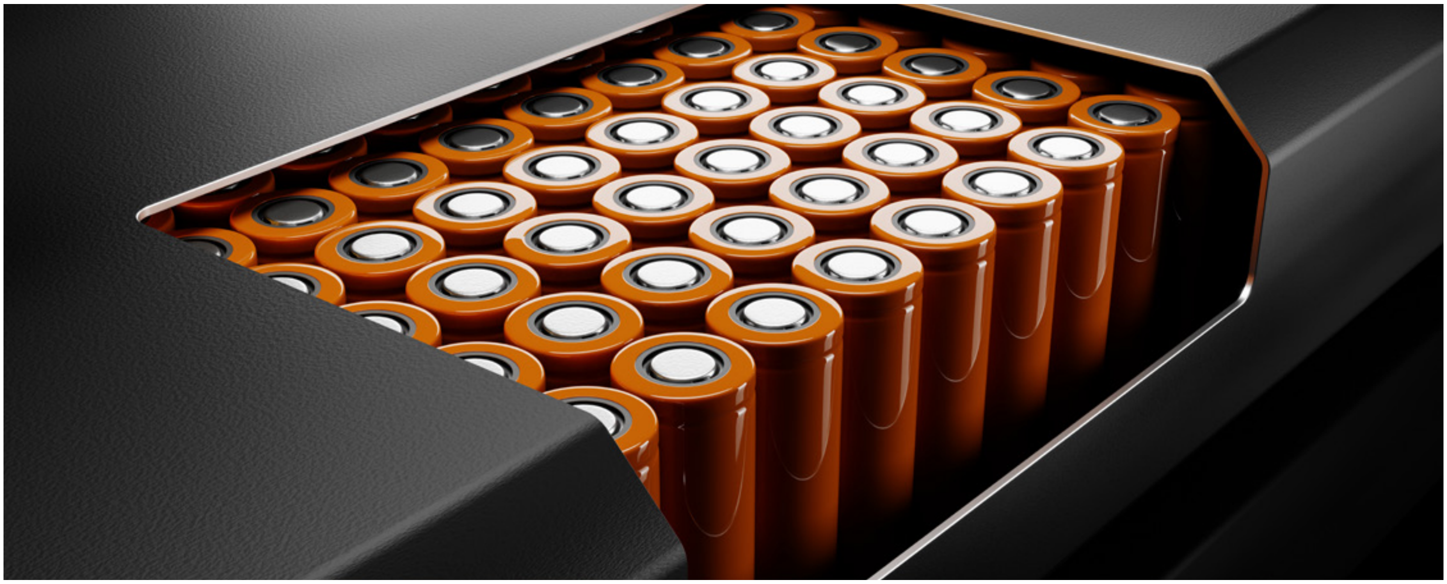
Battery researchers are investigating cathodes and anodes with higher specific capacities while maintaining structural, chemical, and thermal stabilities along with low cost. Thermal analysis enables researchers and engineers to understand the thermal stability (phase transition, melting, and decomposition) of electrode and binder materials for safer and longer lasting batteries across all operational temperatures.

Dry Electrode Processing

Dry battery electrode processing is a growing technique that removes the toxic solvent and lowers the cost of electrode manufacturing. Dry battery electrode processing can be improved with powder rheology coupled with temperature control. Powder rheology measures the flowability, shear, compressibility, and wall friction of dry electrode mix to help optimize mixing and processing conditions. Plus, new temperature control features for powder rheology on the Discovery Hybrid Rheometer allow users to obtain crucial powder insights under application-specific conditions.

Cathode and Anode Resources

Application Note: Safety Evaluation of Lithium-ion Battery Cathode and Anode Materials Using Differential Scanning



Electrode Problem Solving

Challenge	Solution	Technique	What it Measures	TA Instrument
Inhomogeneous and aggregated slurry caused by low quality powders	Measure incoming powder batches for critical parameters like powder cohesion and yield strength	Powder rheology	Power flowability, cohesion and yield strength	Discovery HR with Powder Rheology Accessory
Non-uniform and defects on electrode	Measure viscosity at different shear rates to optimize the coating process	Rheology	Shear viscosity, slurry network structure	Discovery HR
Coating levels or drip as a result of slurry formulation properties	Understand structural deformation, rate of structural recovery during coating process	Rheology	Thixotropy and structure recovery	Discovery HR
Delamination or electrode chipping from poor adhesion	Quantify binder content in final electrode to verify specifications	TGA	Binder and additive composition	Discovery TGA
Low quality of binder	Gain insights on quality and grade of binders	DSC	Melting and glass transition temperature	Discovery DSC
Dry battery electrode processing needs to be optimized	Use powder rheology with temperature control to evaluate dry mix properties	Powder rheology	Power cohesion and processing condition	Discovery HR with Powder Rheology Accessory
Poor Conductivity in Electrode	Characterize conductive material network in slurry	Rheo-Impedance	Impedance under process conditions	Discovery HR Rheo-Impedance Spectroscopy
Predict electrode conductivity from slurry coating	Simultaneous electrical impedance and rheological measurements to gain insight in slurry conductive network	Rheo-Impedance	Conductive network structure under processing conditions	Discovery HR Rheo-Impedance Spectroscopy

Separators

Battery separators are porous membranes that separate the anode and cathode while allowing transport of ions during charge and discharge. Battery separators play a critical role in lithium-ion battery performance, including the prevention of thermal runaway. Some of the requirements for a battery separator include:

- Good electronic insulator
- Minimal electrolyte resistance
- Mechanical and dimensional stability
- Chemical resistance to the electrolyte
- Prevent contact between the electrodes
- Readily wetted by electrolyte
- Uniformity in thickness and properties

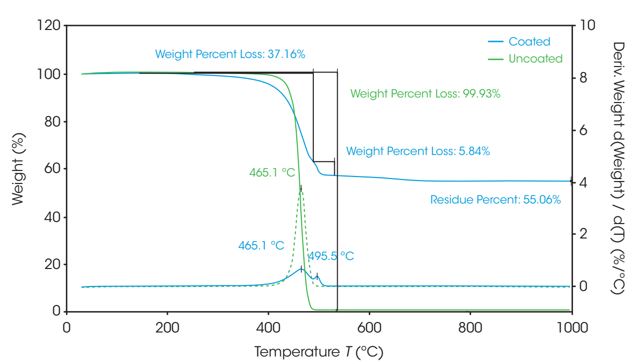
A number of analysis techniques are useful for determining separators' quality, stability, and integrity.

Separator Problem Solving

Challenge	Solution	Technique	What it Measures	TA Instrument
Selecting high quality and performing materials	Thermal assessments to understand material parameters	TGA	Thermal stability, decomposition, polymer and inorganic content	Discovery TGA
		DSC	Melting temperature, crystallinity	Discovery DSC
Separator shrinkage and loss integrity at high temperature	Understand melt integrity, rupture temperature, and orientation effects to aid material selection	TMA	Dimensional change as a function of temperature, shrinkage and rupture temperature	Discovery TMA
Prevent deformation during manufacturing under tension	Understand tensile strength, tensile strain, and rupture point to identify material capabilities and limitation	DMA	Temperature dependent mechanical response, modulus and strength	Discovery DMA

Thermal analysis of separators includes TGA, DSC, and TMA.

Thermogravimetric Analysis (TGA) measures weight change and the rate of weight change as a function of temperature, time, and atmosphere. In separators, TGA helps researchers determine the decomposition temperatures of separators. That data can then help them determine the composition or percentage of individual compounds in the separator, a key step for quality control.



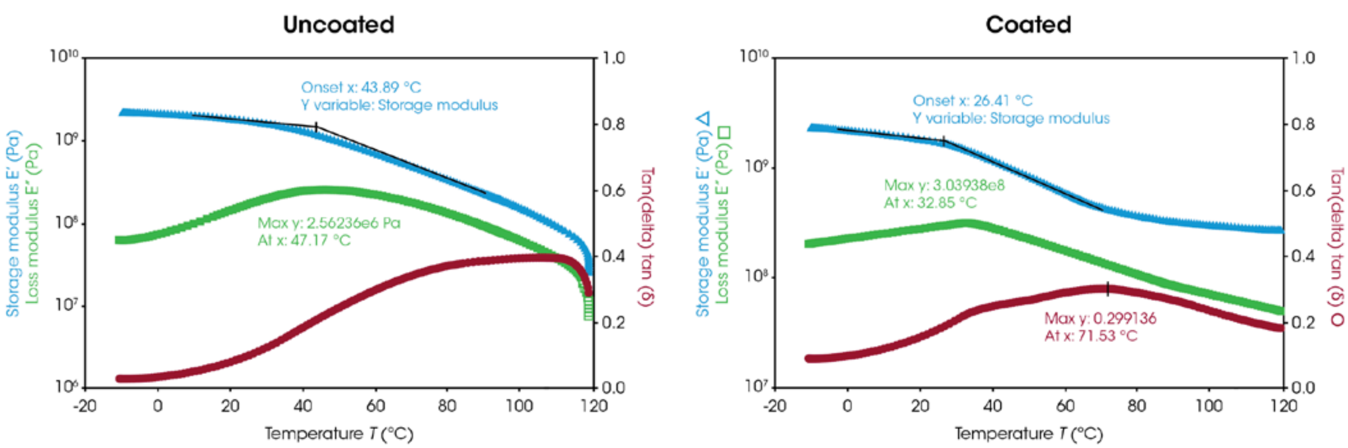
TGA curves of coated separator (blue) and uncoated separator (green)

Thermogravimetric data is critical to setting proper temperature limits for Differential Scanning Calorimetry method development. Differential Scanning Calorimetry (DSC) measures temperatures and heat flows associated with thermal transitions in a material. DSC helps battery separator researchers analyze the melting temperature, impact on melting, and further understand properties of the polymer content determined from the TGA results. DSC data is crucial in predicting how different materials will impact the separators' final properties.

Thermomechanical Analysis (TMA) measures changes in the dimensions of a sample as a function of time, temperature, and force in a controlled atmosphere. TMA measures battery separators' shrinkage onset and rupture temperature. This data helps researchers confidently characterize separators and investigate the potential impact of added coating formulations. High reproducibility in TMA is especially important when measuring safety critical properties such a melt integrity, as a ruptured separator can lead to internal short circuit in a battery that may lead to thermal runaway.

When thermal analysis is combined with mechanical testing, it's possible to understand dimensional stability of a polymer's length and shape, e.g., the polymer separator. This thermal and dimensional insight can help prevent separator failure and ensure battery safety.

For mechanical analysis of separators, researchers use **Dynamic Mechanical Analysis (DMA)** which measures the mechanical properties of materials as a function of time, temperature, and frequency. One particular challenge is preventing undesired elongation of separator material, which leads to deformation. DMA helps researchers understand tensile strength, tensile strain, and rupture point to identify material capabilities and limitation. This data empowers labs to optimize separators for specific applications, choosing adequate materials to offer the desired thermal and mechanical stability at end-use conditions.



Storage modulus, loss modulus, and tan delta curves for uncoated and coated separators

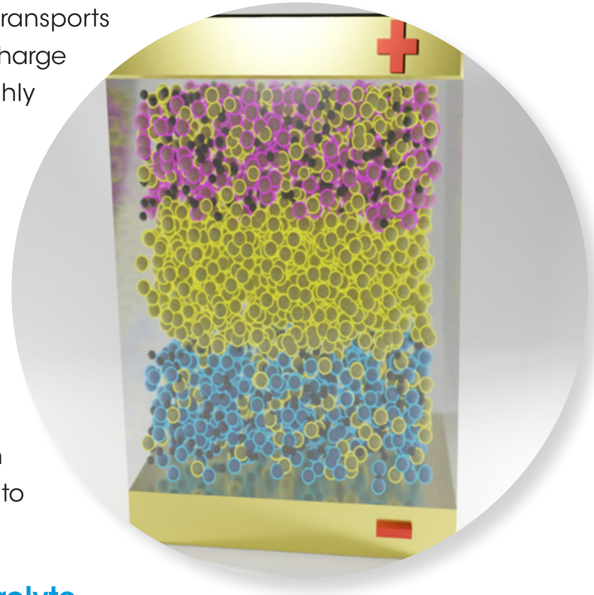
Example Experiments

See how TGA, DSC, TMA, and DMA contribute to efficient and effective separator characterization in these application notes with real experimental data:

Thermal Analysis of Battery Separator Film

Battery Separator Film Development: Impact of Coating

Electrolytes



One of the most critical battery components is the electrolyte, which transports Lithium ions between the cathode and anode during the charge and discharge process. Lithium-ion battery electrolytes are traditionally made of highly flammable solvent with highly reactive lithium salts.

Gel polymer electrolytes are a new formulation of interest as they offer strong electrochemical properties and improved safety over traditional solvent-based electrolytes. Despite these advantages, gel polymer electrolytes still require significant improvements to fully contend with liquid electrolytes.

When electrolytes reach their thermal degradation temperature, they will degrade and generate a highly exothermic reaction. When this reaction happens inside a battery pack, the highly exothermic degradation leads to thermal runaway if the heat is not removed from the battery.

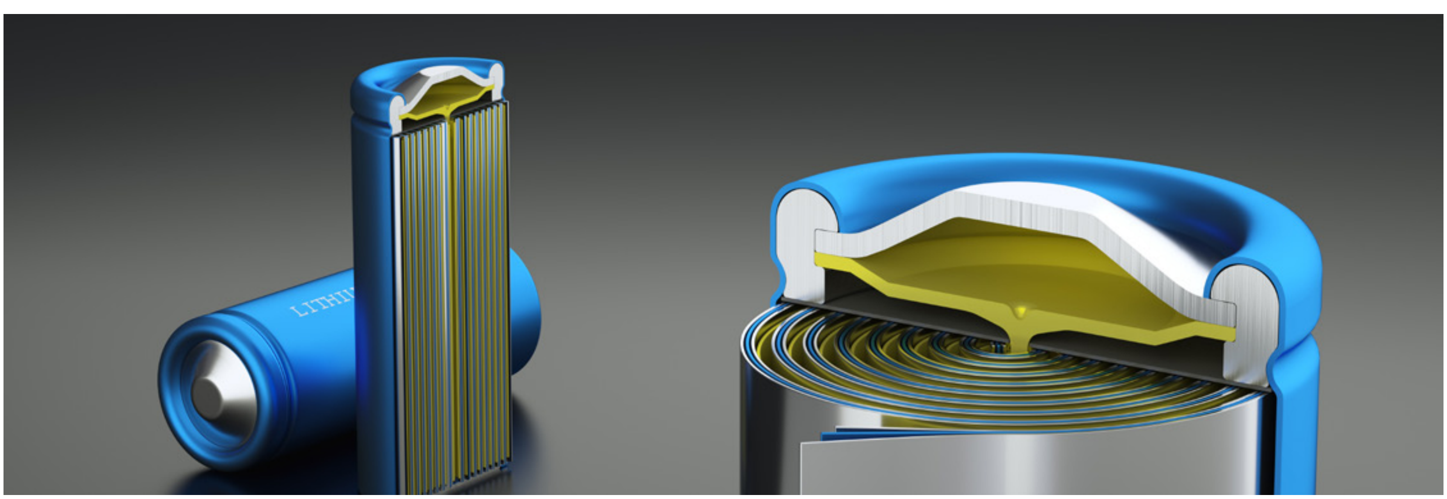
How can you maintain battery temperature to avoid electrolyte degradation and optimize electrolytes for improved battery safety?

Electrolyte thermal stability can be investigated with Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC). Diagnostic thermal stability testing saves time and resources as the safest, most stable electrolytes can be selected early in development.

TGA elucidates the decomposition temperature and solvent loss profile of electrolytes at high temperatures. This data contributes to understanding the overall thermal stability of the electrolyte. Additionally, DSC measurements identify the onset temperature and heat of reaction during exothermic decomposition. The heat of reaction can be used to estimate the heat released during the battery runaway. Combining TGA and DSC helps researchers evaluate the safety hazards of their batteries under chemical abuse and design effective thermal management systems.

How can you optimize the gel polymer electrolyte's mechanical properties?

Gel polymer electrolytes uniquely act as both the electrolyte and the separator, so the mechanical concerns of a separator's ability to separate the electrodes also apply to this electrolyte formulation. Dynamic Mechanical Analysis (DMA) measures the electrolyte's temperature-dependent mechanical response, offering key insights into the electrolyte's tensile strength, tensile strain, and rupture point under specific conditions. DMA helps battery scientists identify their electrolyte's material capabilities and limitations, facilitating stages of electrolyte development through to QA/QC of electrolyte formulation. Gel polymer electrolytes are a new formulation of interest as they offer strong electrochemical properties and improved safety over traditional solvent-based electrolytes. Despite these advantages, gel polymer electrolytes still require significant improvements to fully contend with liquid electrolytes.



How can you facilitate efficient electrolyte manufacturing with effective formulations?

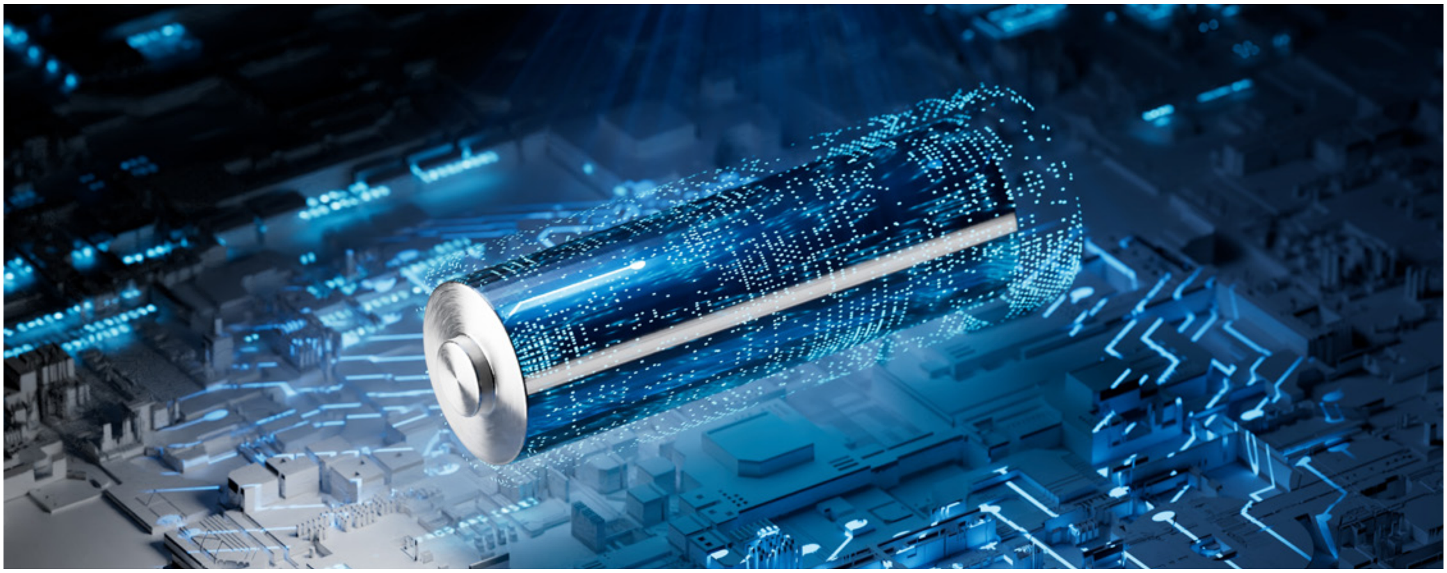
A key area of electrolyte research involves optimizing formulations for ideal pumpability during manufacturing. This step offers ample opportunity for reduced cost and increased efficiency. Rheology enables engineers to measure viscosity and produce electrolyte solvents with optimal pumpability during manufacturing.

Components in lithium-ion batteries, such as electrolytes, lithiated materials and solid-electrolytes interface on electrode, are highly sensitive and reactive materials with atmosphere. Testing and handling of such materials must be done in an inert environment. It can be challenging but necessary to analysis those samples under an inert testing environment to prevent sample integrity is compromised by a brief exposure to nitrogen, oxygen, or water.

TA Instrument Discovery TGA and Discovery Hybrid Rheometers enable glovebox operation for Argon and Nitrogen environments, providing reliable material data of atmosphere-sensitive samples.

Resources

Application Note: Thermogravimetry of Air Sensitive Materials - TA Instruments



Module Pack Materials

Thermal Management System

Battery thermal management systems (TMS) offer the opportunity to improve battery life and reduce overall battery cost – however, they must be carefully designed for this purpose. Maintaining temperature uniformity within a cell, and from cell to cell, requires proper understanding of the thermal conductivity and cooling capacity of the materials used in the TMS.

Optimizing thermal management systems with DSC, thermal conductivity meter and laser flash will reduce the overall cost of the battery pack, plus ensure battery safety and efficiency.

Thermal Interface Materials

Thermal adhesive and phase change materials (PCM) are used to regulate the battery pack temperature. The heat produced by the battery during use poses a threat of inducing thermal events and is detrimental to the performance of the battery itself. The advantage of PCM is they can maintain stable temperature when materials undergo phase changes. Differential Scanning Calorimetry (DSC) is especially helpful in optimizing PCM through measuring phase transitions, heat of fusion, and heat capacity to evaluate the materials cooling capacity.

Thermally conductive adhesive successfully holds the battery in place despite heat and offsets heat that could otherwise impede performance. Laser Flash and thermal conductivity meter are used to measure thermal diffusivity and thermal conductivity. This data helps battery developers select the best materials to dissipate heat.

Successful thermal interface materials must offer excellent thermal conductivity and thermal stability. All of these parameters can be evaluated using material analysis techniques.

Thermal Interface Material Problem Solving

Challenge	Solution	Technique	What it Measures	TA Instrument
Identify impact on thermal management system	Evaluate ability and rate to diffuse heat	Thermal Conductivity meter, Flash	Thermal conductivity, diffusivity, heat capacity, thermal resistance	Thermal Conductivity & Diffusivity Analyzers
Evaluating an adhesive's operating temperature limit	Measure degradation point	Thermogravimetric Analysis (TGA)	Degradation, thermal stability	Discovery TGA
Design and optimize materials and processing conditions	Understand polymer structure and thermal properties	Differential Scanning Calorimetry (DSC)	Curing, glass transition temperature, heat capacity	Discovery DSC
Optimize application conditions	Understand flow and reaction time	Rheology	Curing, viscoelasticity	Discovery HR

Casing and Enclosure

The battery, which commonly weighs 300 kilograms (661 pounds), is mounted to the casing or enclosure. Battery casings are integral for overall battery performance, as they protect all internal components against contamination, adverse atmospheric changes, and damage from impact. Casings are commonly made of steel, aluminum or polymers composite. Battery casings must be molded or formed into their required shapes while providing protection for the inner components, which can be achieved through detailed material analysis and testing.

Casing and Enclosure Problem Solving

Challenge	Solution	Technique	What it Measures	TA Instrument
Predict lifetime and performance under load	Understand material mechanical properties and durability	Dynamic Mechanical Analysis (DMA)	Mechanical property, modulus, creep and fatigue	Discovery DMA ElectroForce Mechanical Test Instruments
Part delamination or failure due to thermal change	Identify dimensional changes that occur with temperature	Thermomechanical Analysis (TMA)	Thermal expansion or shrinkage, thermal expansion coefficient	Discovery TMA
Case degrade or decompose during thermal events	Evaluate thermal stability	Thermogravimetric Analysis (TGA)	Degradation temperature, evolved gas analysis	Discovery TGA

Technique Cheat Sheet

Thermogravimetric Analysis (TGA) measures weight change (loss or gain) and the rate of weight change as a function of temperature, time, and atmosphere. Thermogravimetric data is critical to setting proper temperature limits for Differential Scanning Calorimetry method development. Other common usages include measuring:

- Thermal and oxidative stability of materials
- Moisture and volatile contents
- Composition of multi-component materials
- Decomposition kinetics and estimated lifetime of a product
- Effects of reactive or corrosive atmospheres

Differential Scanning Calorimetry (DSC) measures temperatures and heat flows associated with thermal transitions in a material. Common usage includes investigation, selection, comparison, and end-use performance evaluation of materials in research, quality control and production applications. Properties measured by TA Instruments' DSC techniques include:

- Phase changes
- Glass transition point
- Melting and crystallization
- Heat of reaction (enthalpy)
- Product stability
- Reaction kinetics

Dynamic Mechanical Analysis (DMA) measures the mechanical properties of materials as a function of time, temperature, and frequency. In addition to quantifying viscoelastic properties of materials, DMA can also quantify finished component and product characteristics, reflecting the important contribution that processing has on end-use product performance. DMA is commonly used to measure:

- Mechanical properties
- Modulus and stiffness
- Creep and stress relaxation
- Glass transition temperatures (Tg) and secondary transitions
- Cure and processing optimization
- Filler effects in composites

Rheology is the study of flow and deformation of materials under the influence of an external force or stress. In batteries, rheology measurements are used to ensure successful material processing, optimize product performance, gain insights into complex microstructures and develop novel materials. While viscometers are limited to measuring viscoelasticity, rheometers provide more comprehensive information for battery development, including:

Non-Newtonian Behaviors

- Shear thinning
- Thixotropy
- Yield stress

Viscoelasticity

- Storage Modulus
- Loss Modulus
- Tan Delta

Rheology is especially crucial in forming battery slurries that form uniform, defect-free coatings required for production of consistent, high-quality electrodes with high batch-to-batch repeatability and low scrap rates. Additionally, rheology is used to optimize the manufacturing and performance of gel polymer electrolytes and adhesives.

Isothermal Microcalorimetry (IMC) is a non-specific and non-destructive technique for measuring the smallest reactions in a material during a physicochemical process. This is done by measuring the heat flow from the sample at a constant temperature. Isothermal microcalorimetry offers key battery insights:

- Heat management
- Entropy changes
- SEI formation
- Full cycle parasitics
- Narrow cycle parasitics

For whole battery testing, the **Battery Cycler Microcalorimeter Solution** is able to measure heat flows during battery cycling on a fully integrated, flexible system. Data from the TAM IV Isothermal Microcalorimeter data are both collected and analyzed in one user interface, making it easy to run experiments and analyze results. The Battery Cycler Microcalorimeter Solution is revolutionizing whole cell testing with the highest throughput, fastest data aggregation, and best experimental efficiency of any testing solution available.

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