



Technical Information B-TI 2

Additives for Electrical Energy Storage & Conversion

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BYK Products for Electrical Energy Storage & Conversion

Improving the Production Process and Product Performance

Our additives provide innovative solutions to influence the behavior of materials at the interface. Some of the key steps during the production of

Li-ion batteries, supercapacitors and fuel cells are relying on the dispersion of particles, the control over interfaces, as well as the accurate coating of substrates. Therefore, BYK additives can create value for our customers in the

area of electrical energy storage and conversion. In the field of electrochemical energy storage & conversion we provide solutions for the following components/systems:

BYK Additives for Components and Systems in Electrochemical Energy Storage & Conversion

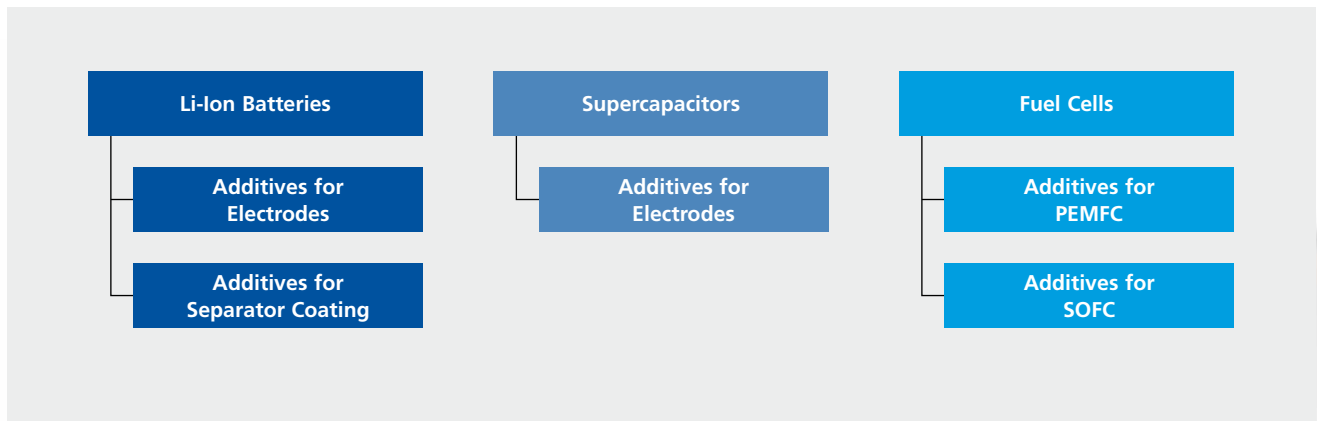


figure 1



Technical Service – Close to our Customers

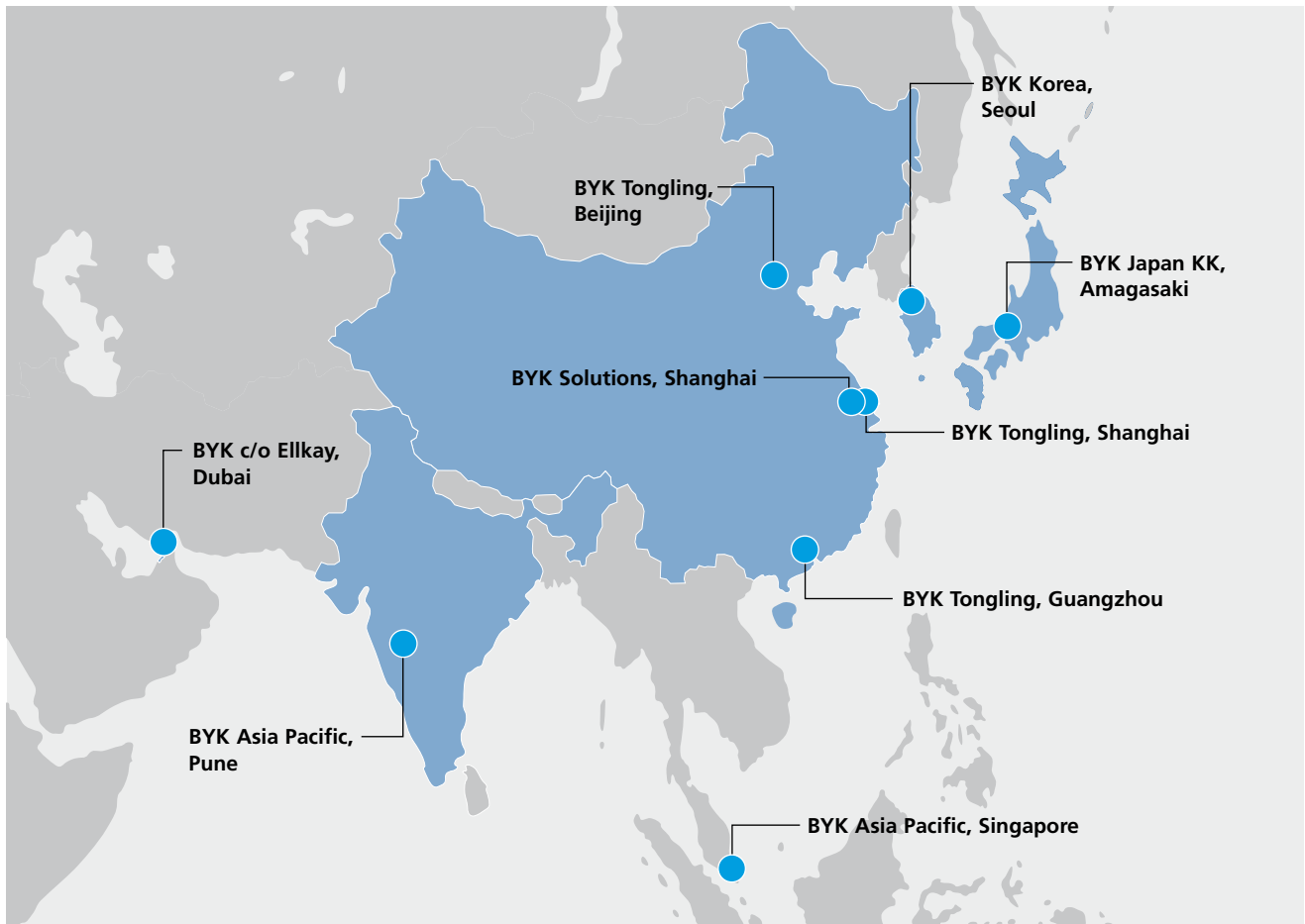
The focus of our activities in electrochemical energy storage & conversion is lying on **Li-ion batteries**. In order to be close to our customers in Asia we have opened our electrochemical laboratory in Amagasaki, Japan. The laboratory

serves as BYK’s technology development and support center for additives used in electrochemical energy storage & conversion systems.

Significant investment has been made to be outfitted with state-of-the-art equipment for:

- Electrode slurry preparation
- Characterization of electrode slurries and coatings
- Coating of electrodes or separators
- Li-ion cell tests

BYK Laboratories in Asia



■ Countries with BYK presence
■ BYK service laboratories

figure 2

BYK Additives for Li-Ion Batteries

BYK delivers additives for the manufacturing of **electrodes** and **ceramic coated separators** of Li-ion cells. Although our substances are only

added in small quantities, they strongly contribute to lower the production costs as well as improving the product properties and safety of the cells.

Where to Find BYK Additives in Li-Ion Batteries?

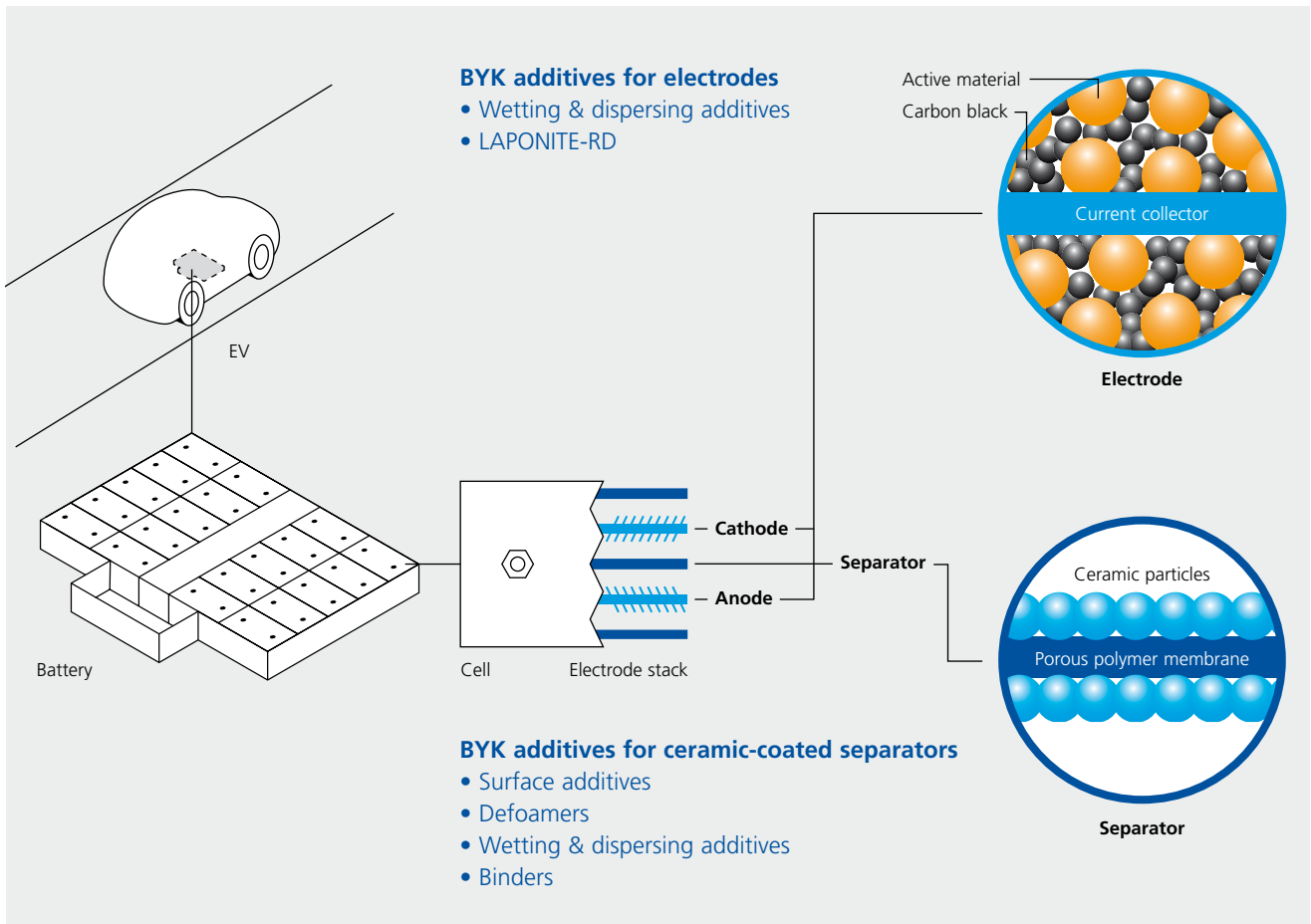


figure 3

Additives for Electrodes – Wetting & Dispersing Additives

Dispersion of Conductive Carbon Structures

In battery electrodes, conductive carbon structures (e.g. carbon black, carbon nanotubes, or graphene) are added to form a composite structure with the active material and binder in order to assure a high electronic conductivity.

Carbon black forms agglomerates in its powder form (figure 4) and during the electrode slurry preparation it needs to be **dispersed** into smaller **aggregates** as otherwise the volume resistivity of an electrode coating including active material and binder is high (state I, figure 5). The resistivity is reaching a minimum when the carbon black agglomerates are dispersed into aggregates which are homogeneously distributed in the electrode and form an interconnected network (state II, figure 5). Further grinding into separated aggregates, however, will result in an increasing electrode resistivity, due to the loss of long-range conductive pathways in the electrode (state III, figure 5).

Agglomeration of Carbon Black

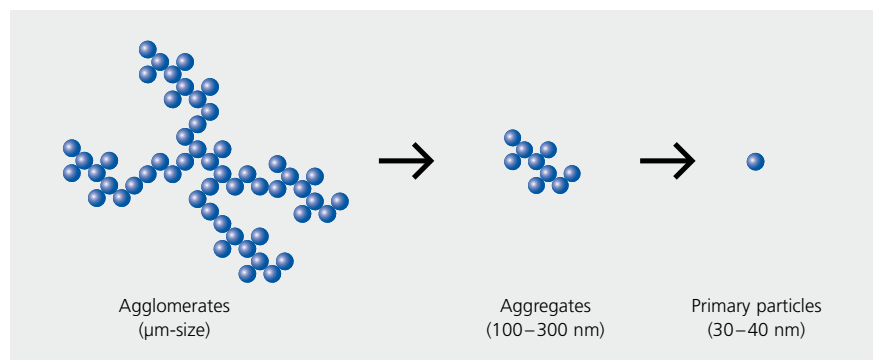


figure 4

Scheme Representing Correlation Between Volume Resistivity of Electrode Coatings and Aggregate Size of Carbon Blacks

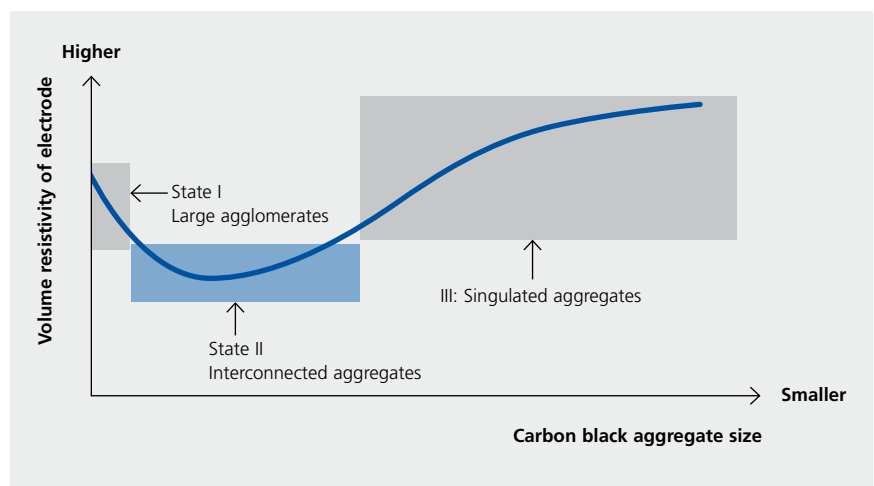


figure 5

Polymeric Wetting & Dispersing Additives

Wetting & dispersing additives combine two functionalities in one polymeric structure (figure 6). Surface-affinic functional groups of the polymers adsorb on the particle surface whereas solvent affinic parts are interacting with the solvent and binder. Thereby they accelerate the incorporation of solid particles into a liquid media and stabilize dispersed particles from re-agglomeration. The proper spacing between the particles is maintained by **electrostatic** repulsion and/or **steric hindrance** in order to assure storage stability of slurries (figure 7).

Polymeric Wetting & Dispersing Additive Adsorbed on Particle Surface and Selection of Particle-affinic Groups

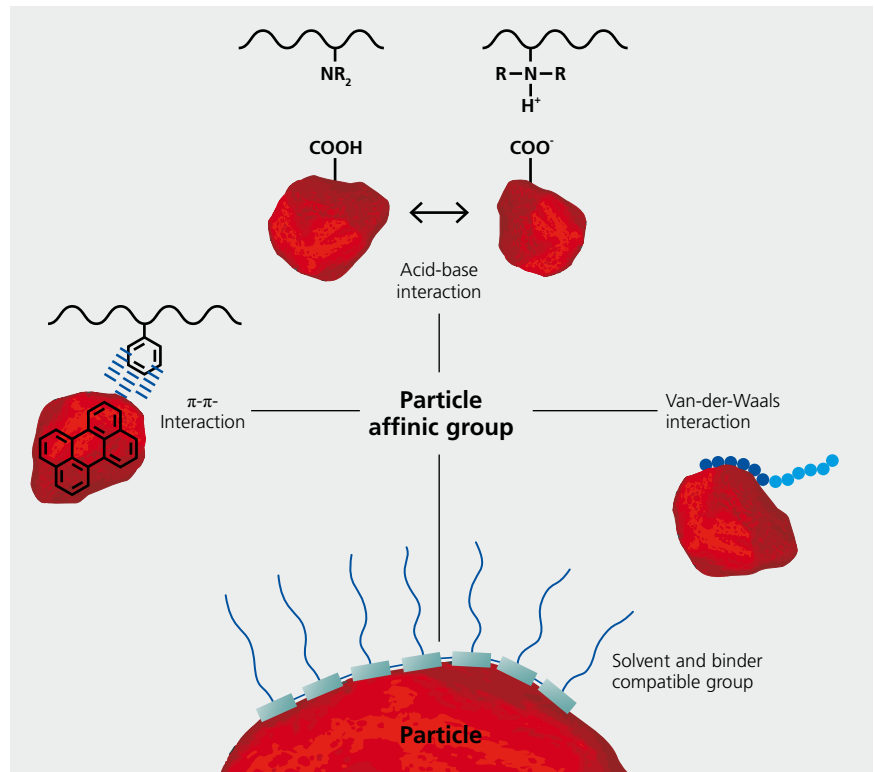


figure 6

Stabilization Mechanisms of Wetting & Dispersing Additives

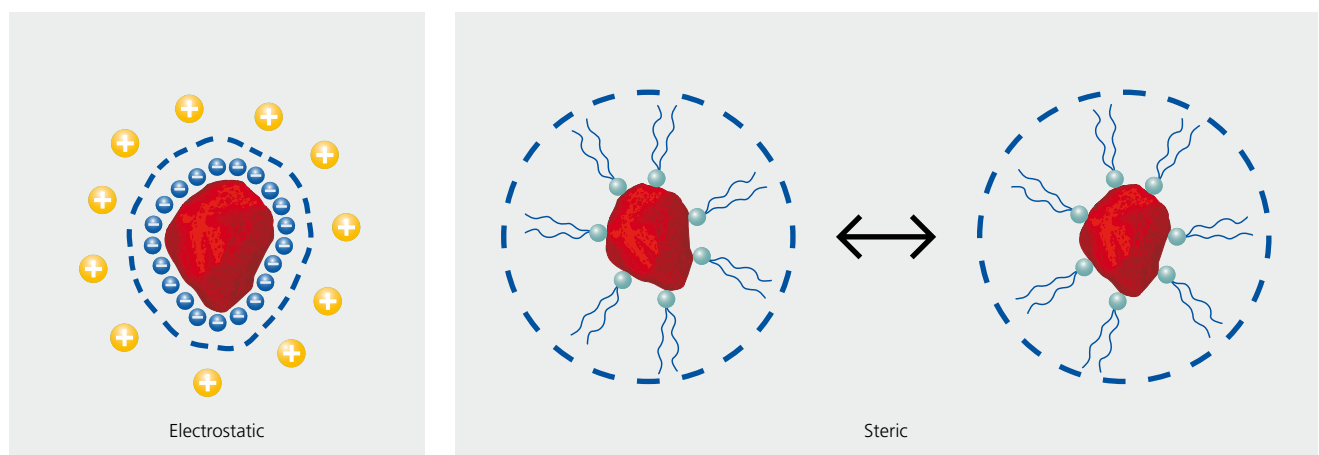


figure 7

› Additives for Electrodes – Wetting & Dispersing Additives

Wetting & Dispersing Additives for Pastes of Conductive Carbon Particles

9% Ketjen Black in NMP



Without wetting & dispersing additive

With wetting & dispersing additive

figure 8

Why Use Dispersing Additives in Electrodes?

Wetting & dispersing additives **reduce** the **viscosity** of dispersions significantly. As an example, figure 8 depicts a 9% dispersion of a Ketjen Black in N-Methyl-2-pyrrolidone (NMP) without and with additive. The sample without is a sticky paste, whereas the sample including 10% of additive on the Ketjen Black is a low viscous fluid which shows excellent storage stability. Wetting & dispersing additives are therefore used to prepare **concentrates of conductive carbon structures**. In electrode slurries including active material and binder they also effectively reduce the viscosity so that **higher solid contents** are accessible. Furthermore, thanks to their stabilizing effect the addition of wetting & dispersing additives drastically **shorten the grinding time**

(figure 9). Figure 10 depicts the cross-sectional SEM-images of LiFePO₄ (LFP) cathodes prepared without and with additive. In case of the sample including additive, the targeted carbon black aggregate size is already reached when the sample without additive still shows carbon black agglomerates and poor conductivity.

The combination of higher **solid contents** of electrode slurries and reduced grinding time **lowers energy and labour cost** during electrode production. BYK offers wetting & dispersing additives for water- and solvent-borne processes.

Scheme Representing the Influence of Wetting & Dispersing Additives on Grinding Time

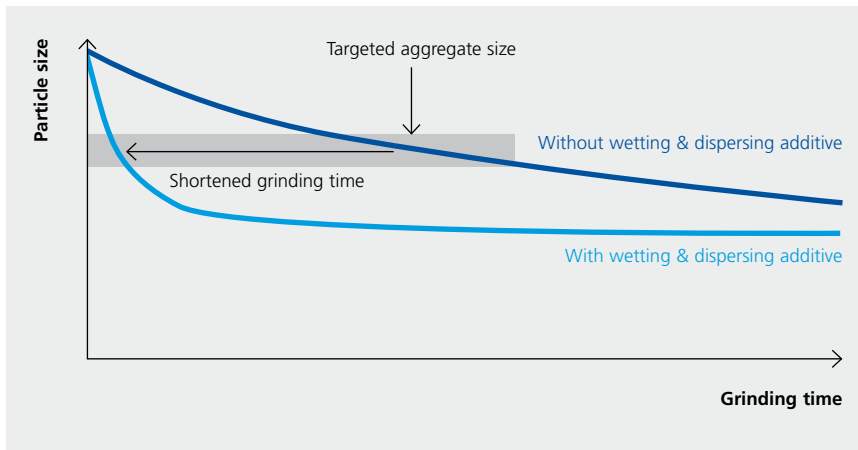


figure 9

Electrochemical Performance

The additives can be used in electrodes without any negative effect on cycle-life or C-rate performance. Figure 11 shows the cycle-life and C-rate performance of graphite/LFP-cells. Polymeric wetting & dispersing additives can further partially replace the conventional binder so that the energy density keeps constant. Wetting & dispersing additive (0.75 wt. %) partially substituted the Polyvinylidene Fluoride (PVDF) and was used for preparation of the LFP-cathode (90 wt. % LFP, 5 wt. % carbon, 5 wt. % PVDF/wetting & dispersing additive).

Cross-sectional SEM-images of LFP-cathodes

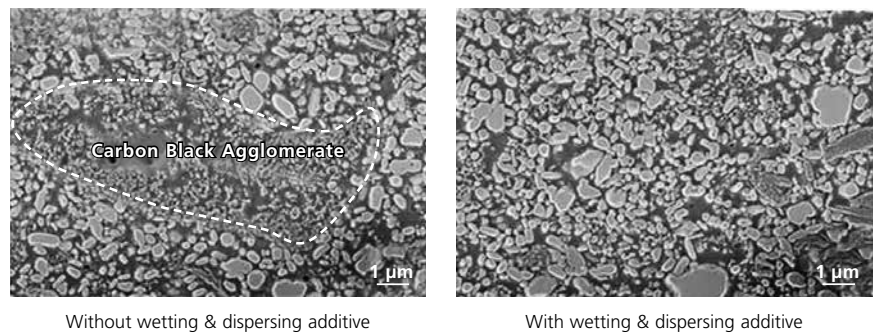
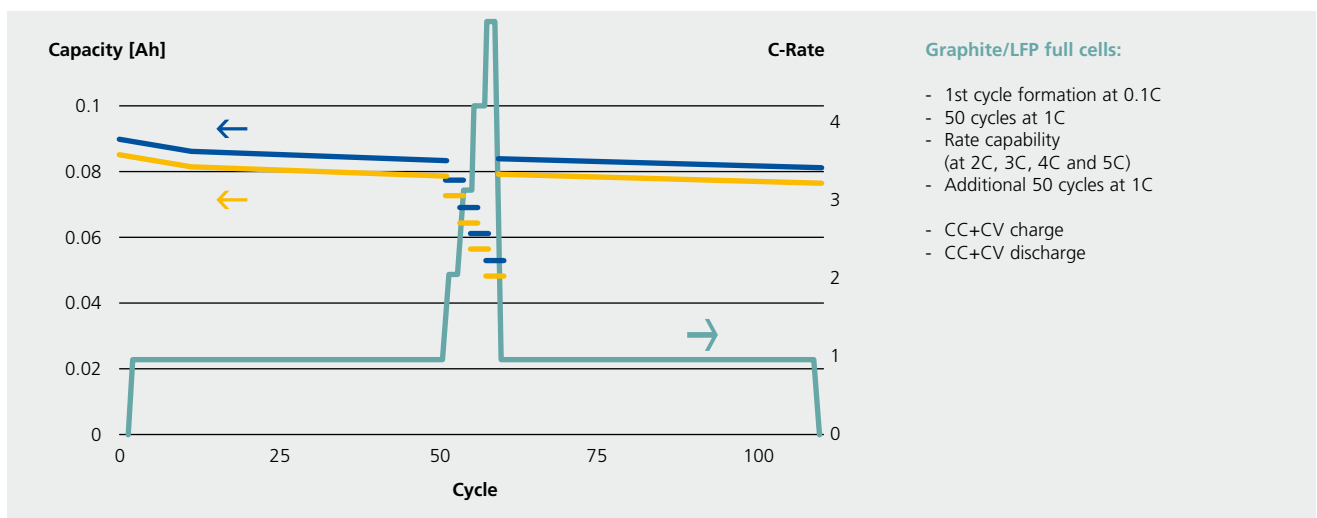


figure 10

Cycle-life and C-rate Performance of Graphite/LFP-cells – The Wetting & Dispersing Additive was Used in Cathode



■ BYK Product ■ Control

figure 11

Wetting & Dispersing Additives

- Used for pastes of conductive carbon structures (carbon black, CNTs, etc.)
- Help to increase slurry solid content
- Shorten grinding time
- Reduce energy and labour cost

Additives for Electrodes – LAPONITE-RD

What is LAPONITE-RD?

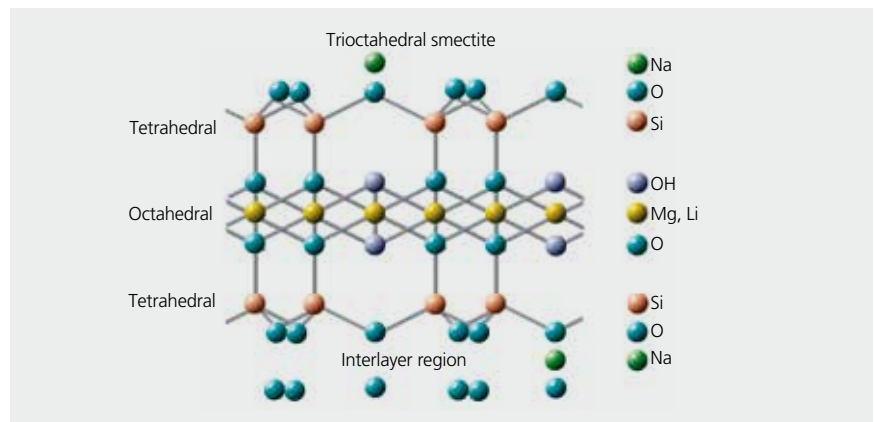
LAPONITE-RD is a **synthetic phyllosilicate of high purity** that is delivered as white powder. LAPONITE has a layer structure which is in the form of disc-shaped crystals (figure 13). The empirical formula can be given with: $\text{Na}^{+}_{0.7}[(\text{Si}_{8}\text{Mg}_{5.5}\text{Li}_{0.3})\text{O}_{20}(\text{OH})_4]^{-0.7}$ (figure 12).

In delivery form the crystals are arranged into stacks which are held together electrostatically by sharing of sodium ions in the interlayer region between adjacent crystals. A dilute dispersion of LAPONITE in deionised water may remain a low viscosity dispersion of non-interacting crystals for long periods of time.

Synergistic Effect with Organic Thickening Agents

When used in combination with polymer thickeners, the **charged LAPONITE particles** develop **electrostatic associations** with oppositely **charged sections on the molecules of polymer co-thickener** (figure 14 and figure 15). This additional bonding mechanism of particle to polymer interactions result in **synergistic effects with carboxymethylcellulose (CMC)** which enables to formulate aqueous electrode slurries with high stability (figure 17). Further the interaction remain active in the dried electrode coating and results in **improved adhesion strength of electrode coatings** (figure 18).

Idealized Structural Formula of LAPONITE-RD



Empirical formula of LAPONITE RD: $\text{Na}_{0.7}^{+}[(\text{Si}_{8}\text{Mg}_{5.5}\text{Li}_{0.3})\text{O}_{20}(\text{OH})_4]^{-0.7}$

figure 12

Representation of a Single LAPONITE-RD Crystal – Product as Powder and Dispersed in H₂O (From Left to Right)

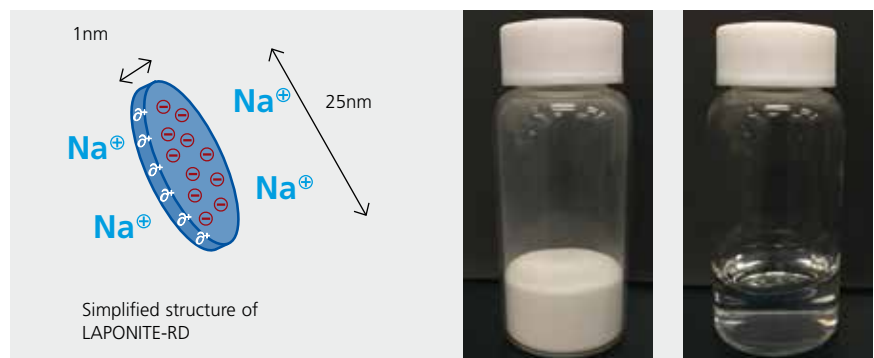
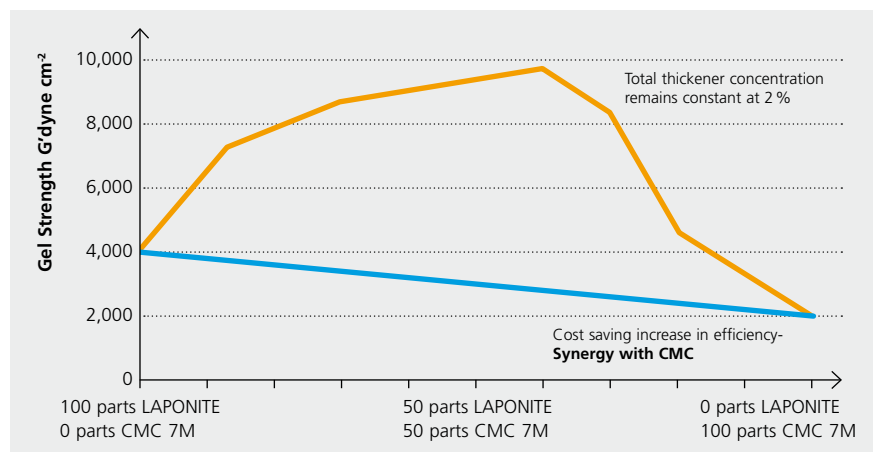


figure 13

Synergistic Effect with CMC



Actual gel strength Calculated gel strength

figure 14

Reinforcement of Binder Due to LAPONITE-Polymer Interaction

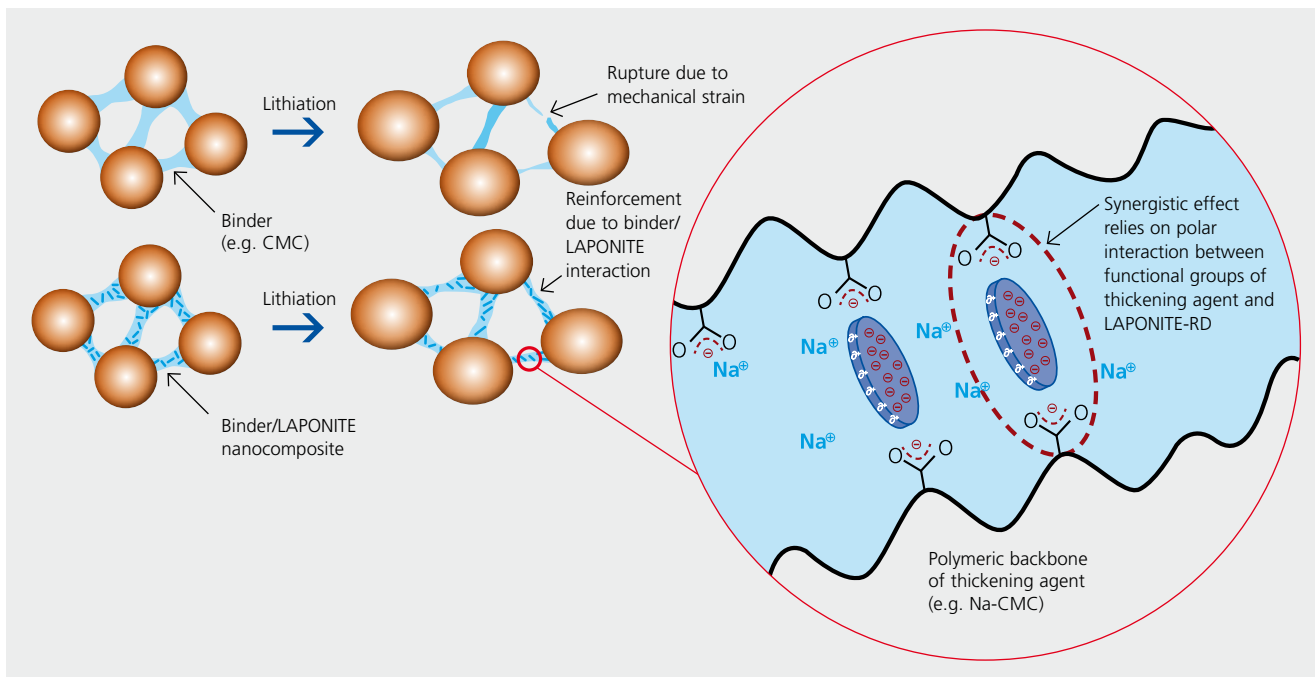


figure 15

LAPONITE-RD as an Additive in Electrodes

LAPONITE-RD can be used in **aqueous electrode coating formulations** in combination with conventional organic binders such as carboxymethylcellulose (CMC) and styrene butadiene rubber (SBR).

Replacement of 20 % of CMC by LAPONITE-RD in graphite anode slurries (figure 16), which corresponds to 0.3 % in the coating, prevent sedimentation of anode materials well as shown in figure 17.

Composition of Graphite Anode Slurries

	CMC	CMC/ LAPONITE-RD
CMC	1.5 g	1.2 g
LAPONITE-RD	-	0.3 g
H₂O	100 g	100 g
Carbon Black	1.7 g	1.7 g
Graphite	94.5 g	94.5 g
SBR	2.3 g	2.3 g
Solid content (%)	50	50

figure 16

› Additives for Electrodes – LAPONITE-RD

Synergistic Effect with CMC Results in High Storage Stability

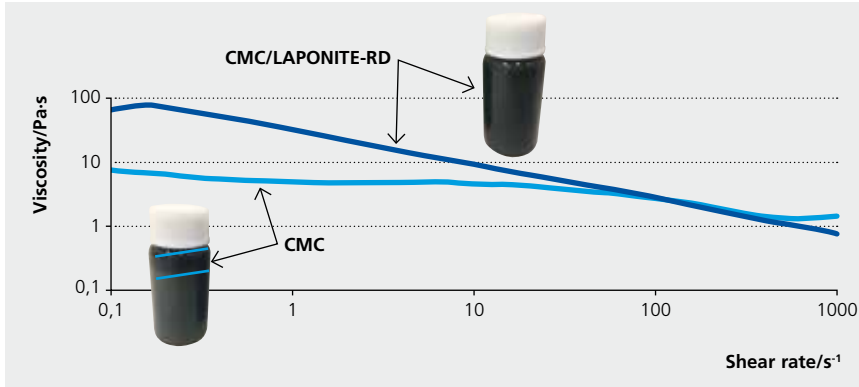


figure 17

Synergistic Effect with CMC Results in Improved Adhesion Strength

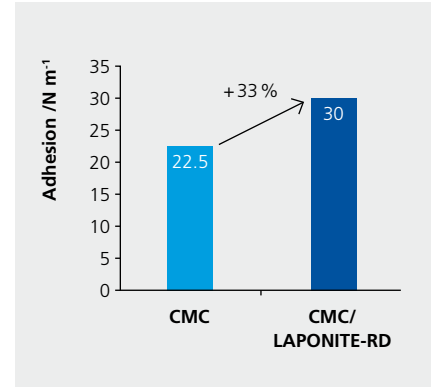


figure 18

Properties of LAPONITE-RD

- High purity
- Improved slurry stability
- Improved adhesion strength
- Improved electrode wettability

Additives for Ceramic-coated Separators

Product Groups Applied in Separator Coating

Polymer separators or electrodes are coated with a thin layer of ceramic particles in order to improve the safety of Li-ion cells. BYK supplies additives

that work on the different interfaces in order to improve the production process and properties of the coating. As shown in figure 19, surface additives work at the ceramic coating-separator-interface, defoamers at the air-dispersion medium-

interface, wetting & dispersing additives at the ceramic particle-dispersion medium-interface and, binders between particles and at the ceramic coating-separator-interface.

Product Groups Applied in Separator Coatings – Working at the Interfaces

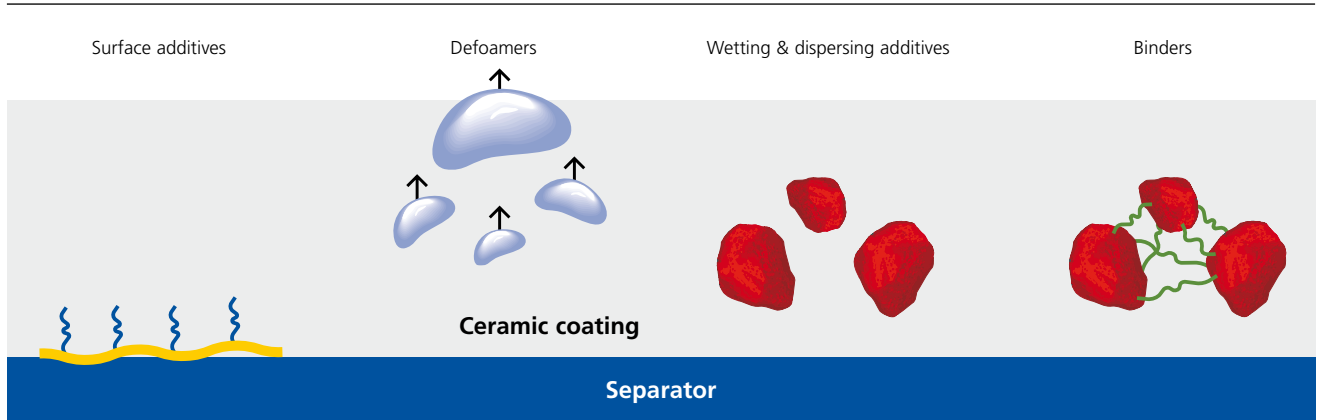


figure 19

Wetting & Dispersing Additives

BYK's polymeric wetting & dispersing additives result in a fine and homogeneous distribution of solid particles in liquid media and ensure the long-term stability of such systems (figure 20).

Dispersing additives adsorb onto the particle surface and therefore maintain proper particle spacing through electrostatic repulsion and/or steric hindrance, thus reducing the tendency towards agglomeration. In some systems, a connection between the dispersed particles can be advantageous, e.g. to prevent sedimentation of the particles.

Using a hydrophobic wetting & dispersing additive is also preferable as the moisture uptake of the battery is reduced. In some cases, a reduction in moisture uptake of more than 30 % can be achieved (figure 21).

BYK offers several types of hydrophobic wetting & dispersing additives to meet a variety of requirements.

Effect of Wetting & Dispersing Additives



figure 20

Reduction of Water Content in Separator with Hydrophobic Wetting & Dispersing Additives

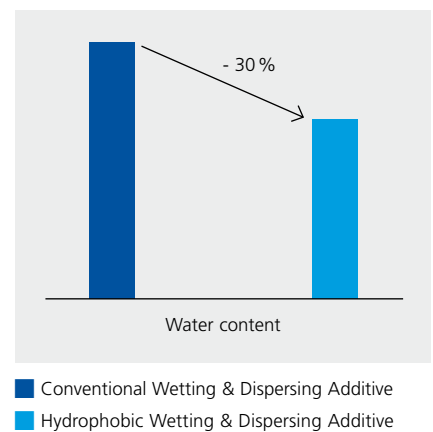


figure 21

› Additives for Ceramic Coated Separators

Defoamers

The dispersion process of ceramic particles is often accompanied by the formation and stabilization of foam (figure 22). Prior to coating, **defoaming of the ceramic dispersion is required** to ensure a **defect-free coating** without pinhole formation due to encapsulated foam bubbles.

BYK supplies different types of defoamers (e. g. mineral oil defoamers, silicone defoamers, and silicone-free polymer defoamers) that help to minimize foam formation and improve the defoaming process.

Defoaming of Ceramic Slurries



Without defoamer



With defoamer

figure 22

Surface Additives

These additives can be applied in order to **improve the wetting of hydrophobic surfaces with aqueous ceramic slurries, the levelling of the thin coatings, and to adjust the surface energy of the coating** in order to provide good wetting with the electrolyte. The combination of a non-polar polydimethylsiloxane and a hydrophilic polyether group in silicone surfactants (figure 23) significantly reduces the surface tension of aqueous slurries. This **improves the coating speed and adhesion of the coating** (figure 24, 25 and 26).

In addition to silicone surfactants, BYK offers silicone-free wetting agents that are based on alcohol alkoxylates.

Structure of a Silicone Surfactant

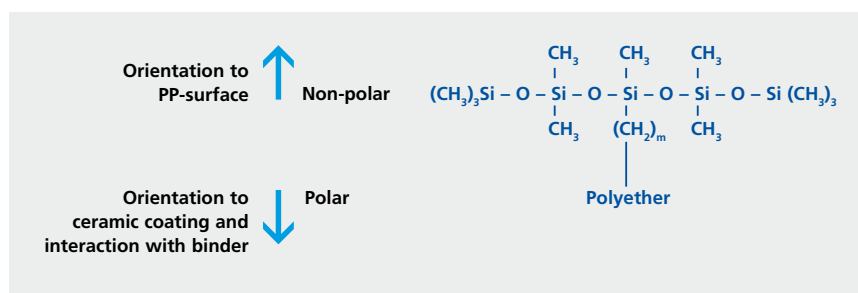
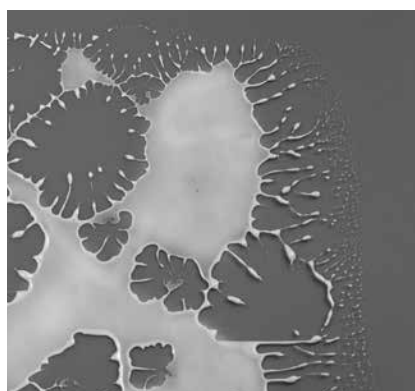


figure 23

Improved Wetting



Without surface additive



With surface additive

figure 24

Improved Wetting of an Aqueous Ceramic Coating Slurry on a PP-separator Due to the Addition of a Wetting Agent

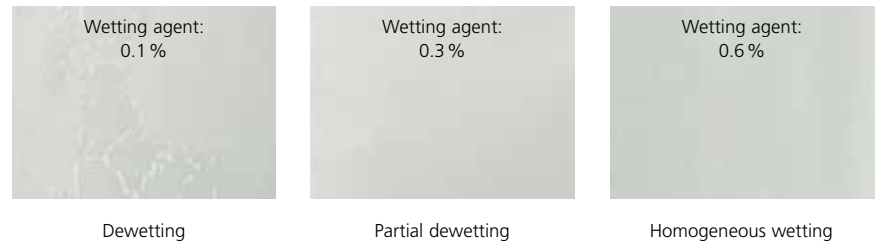


figure 25

Influence of Wetting Agent on Adhesion Strength

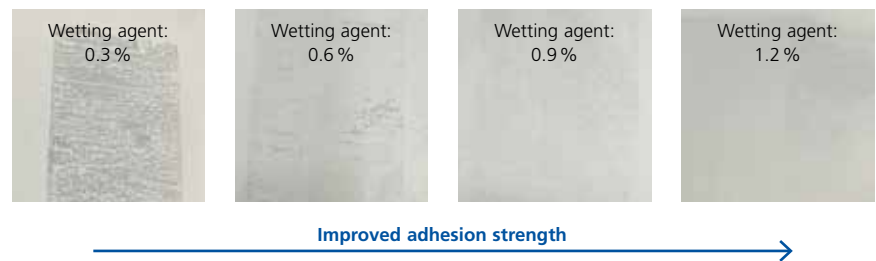


figure 26

Binders

Binders can fix the ceramic particles onto separators. The binder quantity depends on the ceramic formula. BYK offers water-borne type binders, and these are produced by our own technologies.

PVDF Coatings

Fixing electrodes on the separator is important for battery safety, and PVDF coatings are often applied for this purpose. BYK offers a variety of additives for water-borne PVDF coatings. For example, Wetting & Dispersing additives can help to disperse PVDF particles in water, and surface additives, defoamers and binders can be used to improve the properties and the quality of the coating.

Influence of Wetting & Dispersing Additive for PVDF Coatings

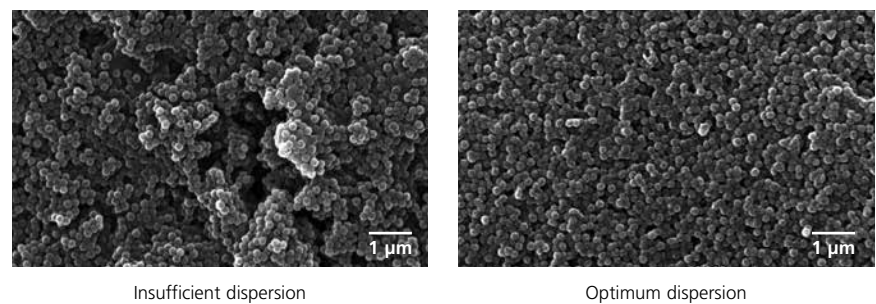


figure 27

Formulation Recommendation

PVDF	26.7 %
Water	67.8 %
Wetting and dispersing additive	1.6 %
Binder	2.4 %
Defoamer	0.4 %
Surface additive	0.5 %
Rheology additive	0.6 %

figure 28

For more information about our additives and instruments, as well as our additive sample orders please visit:

www.byk.com

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Additive Guide



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