EVONIK SOLUTIONS FOR BATTERY ELECTRIC VEHICLES

**INNOVATE MOBILITY –
WE PROVIDE THE CHEMISTRY.**

EVONIK
Leading Beyond Chemistry

LEADING BEYOND CHEMISTRY TO IMPROVE LIFE, TODAY AND TOMORROW

Evonik is one of the world leaders in specialty chemicals. The company is active in more than 100 countries around the world. Evonik goes far beyond chemistry to create innovative, profitable and sustainable solutions for customers. More than 32,000 employees work together for a common purpose: **We want to improve life, day by day.**

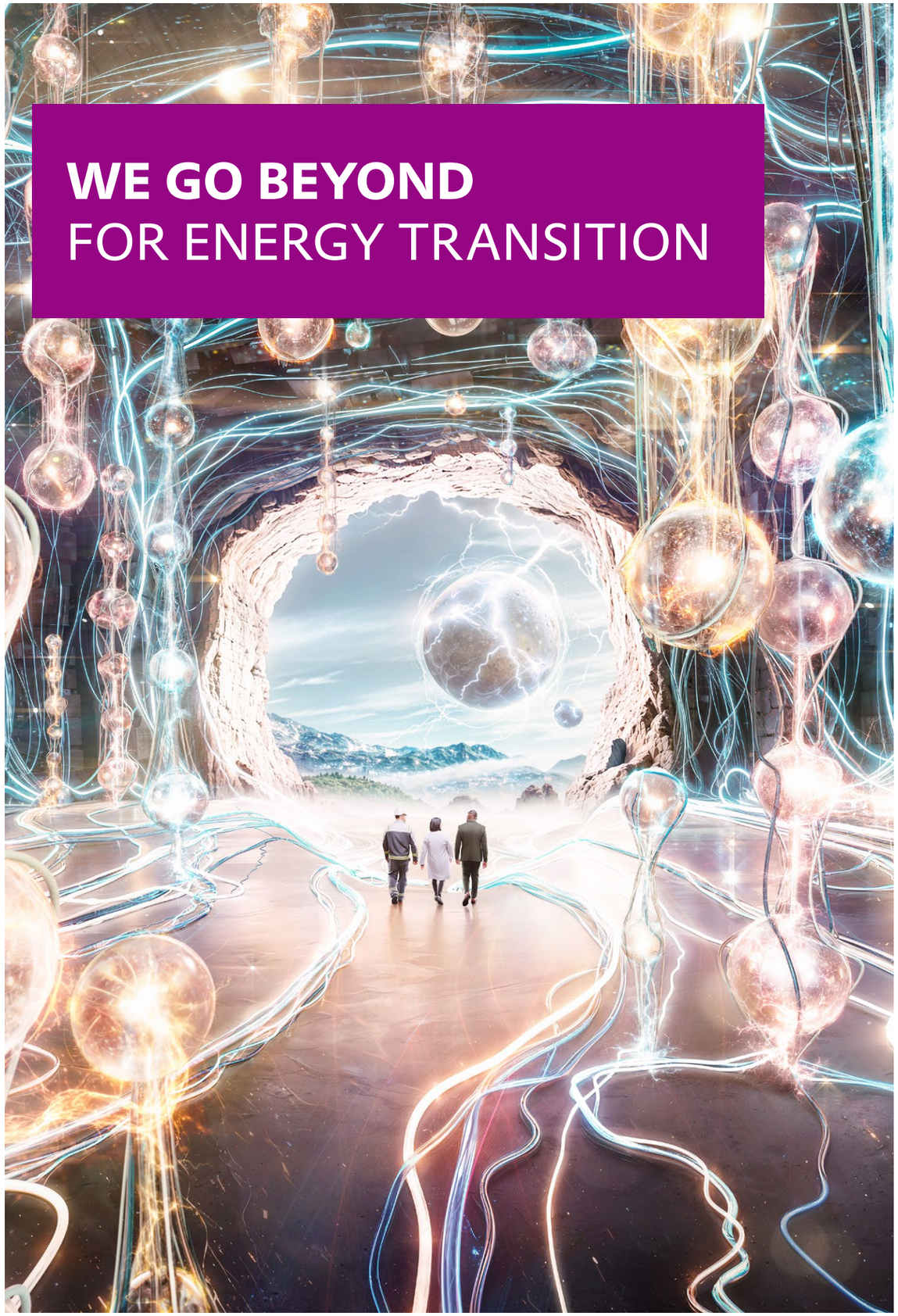
NEXTGEN

Evonik is embarking on the next phase of its strategic transformation.

The electric vehicle market has seen significant growth around the world, helping to further achieve carbon neutrality goals for a greener future. The shift from traditional petrol-powered combustion engines to hybrid and full EVs has placed lithium-ion batteries at the heart of modern e-mobility solutions.

Evonik's product portfolio for electric vehicle batteries includes a wide range of chemistries and high-performance materials. With raw materials, additives, process enablers and ready to use products, our products improve the performance of our customers' offerings across the entire electric vehicle battery value chain, anywhere it is needed: battery packs, battery cells and battery management systems and battery recycling. And with our next generation solutions, we make the electric vehicle batteries safer and long-living.

Learn more about how we support to boost EV batteries and our chemistry solutions for automotives, please visit:
https://automotive.evonik.com/en



EVONIK GLOBAL LITHIUM-ION BATTERY CENTER (LIB-C)

Enhancing service and develop tailor-made solutions for the fast-developing EV battery industry

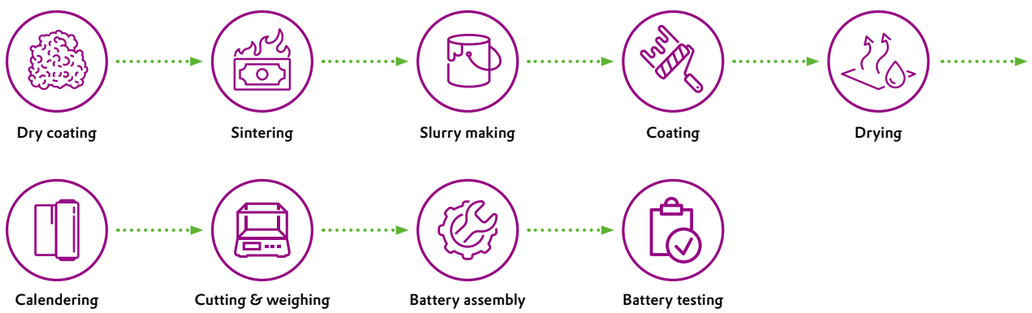
Evonik global Lithium-ion Battery Center (LIB-C) located in its Shanghai Innovation Park, was put into operation in 2022. As the first global facility for the lithium-ion battery industry, the center develops innovative materials for batteries with higher energy density, safer performance and longer life.

The new Shanghai Lithium-ion Battery Center is part of Evonik's global R&D network. It merges the expertise across various businesses on innovations for cathode, anode and separator materials and electrode preparation technologies. The center is equipped with state-of-the-art facilities including material preparation and characterization, coin- and pouch-cell pilot lines and battery test equipment, where Evonik experts are able to conduct the research and development work on next-generation battery materials, cells and technologies.

The center is equipped with state-of-the-art facilities to conduct research and experiment of key steps for the battery making process from material preparation to performance testing.

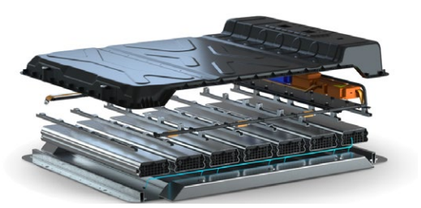
OUR STATE-OF-THE-ART FACILITIES CAN CONDUCT EXPERIMENT OF KEY STEPS FOR THE BATTERY MAKING PROCESS

Electrode and cells



Separator coating

EVONIK MAKES THE ELECTRIC VEHICLE BATTERIES
SAFER AND LONG-LIVING



BATTERY PACK

ANCAMIDE® and ANCAMINE®
2K epoxy curing agent
Provide excellent adhesive and mechanical property in EV battery structural adhesives and thermal conductive adhesives.

NOURYBOND® 382
Adhesion promoter of PVC plastisol for EV battery underbody coating, especially for low temperature or short time baking condition.

VESTALITE® S, the new curing agent
Allows using optimized epoxy SMC technology for structural lightweight applications.

KOSMOS® and DABCO® series
Organo-tin and bismuth metal catalysts can optimize material properties and curing behavior.

TEGOSTAB® and POLYCAT® SA Series
- Silicone surfactants and amine catalysts for PU froth foam.
- Amine catalysts for potting and froth foam

ORTEGOL® Series
Dispersants and adhesion promotors for PU thermal conductive adhesive and others.

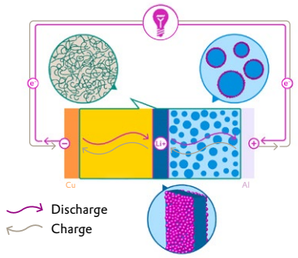
AEROSIL® fumed oxides
Provide excellent rheological and reinforcement properties in EV battery structural adhesives.

Dynasylan® organofunctional silanes
Provide excellent adhesion and crosslinking properties in structural adhesives and thermal conductive adhesives.

POLYVEST®
Liquid rubber used as highly reactive crosslinking binders or additives for 2K PU for gap filler or thermal conductive adhesive for EV-battery assembling.

VESTOPLAST®
APAO for hotmelt adhesive for cell structure bonding, welding point protection and electrode tab bonding etc.

TEGO® Therm
Thermal insulation granules and heat-stable silicone hybrid binder for fire-resistant coatings for EV battery housings & covers.



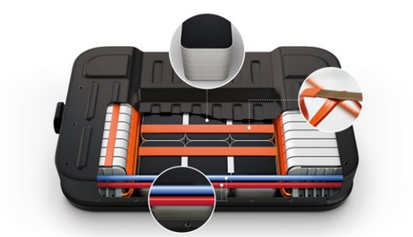
BATTERY CELL

Anode
- Carbon-based materials with addition of silicon.
- TEGO® Surten E series dispersant and flexing agent.

Cathode
- Cathode active materials dry coated with AEROXIDE® improve performance and life-time of Li-ion battery cells.
- TEGO® Surten E series dispersant and flexing agent.
- P84® solution binder and dispersant.

Separator
- Microporous membrane coated with AEROXIDE® to improve safety of Li-ion battery cells.
- TEGO® Surten E series wetting agent.

Gel polymer electrolyte
- Immobilized by functional AEROXIDE®.



BATTERY MANAGEMENT SYSTEM

AEROSIL® fumed oxides
Provide excellent rheological and reinforcement properties in EV battery structural adhesives.

AEROXIDE® fumed metal oxide
Functional additives for silicones, adhesives & sealants, and thermal insulation for EV battery pack assembly.

Dynasylan® organofunctional silanes
Provide excellent adhesion and crosslinking properties in structural adhesives and thermal conductive adhesives.

VESTAMID® PA12
The UL94 flame retardant polymer provides excellent high-voltage insulation properties for power busbar applications according to future safety requirements in EV.

VESTAMID® PA12 tubing systems
Contribute to an ideal thermal management of HV battery, e-motor, inverter and a well-tempered overall ambience of the car.

Polymer VS and TEGOSIL®
Silicone raw materials and additives for thermal management.

VISCOBASE®
Dielectric thermal management fluids for improved battery lifetime, thermal efficiency and safe operation.

EVONIK PROVIDES VARIOUS SOLUTIONS FOR **ELECTRIC VEHICLE BATTERY INDUSTRY**

Area		Products	Applications	Benefits	Page
Battery Pack	**Battery Box**	Curing agent	Epoxy SMC based battery enclosure	Easy processing, lightweight design and low emissions	9
		Epoxy curing agent	Epoxy 2k curing agent	Low viscosity, excellent adhesion and flexibility, fast curing speed	10
		Adhesion promoter	PVC plastisol adhesion	Improving adhesion and baking under low temperature or short time, low odor, phthalates and arene free	
		APAO	Hotmelt adhesive for cell structure bonding, welding point protection, electrode tab bonding etc	Excellent electrolyte resistance, high thermal stability, excellent adhesion and hot tack properties, good hydrolytic and UV stability, bonding to various substrates especially on PP without pretreatment	11
		Liquid rubber	2K PU for gap filler or thermal conductive adhesive for EV-battery assembling	Low viscosity, adjusted thixotropy, excellent chemical resistance to acids and bases, high water resistance, low moisture and oxygen permeability, good flexibility	
		Silane adhesion promoter	EP, PU, SMP and other adhesives and sealants	Excellent adhesion and curing properties	12
		Polyurethane catalysts	PU adhesives & sealants & foam	Help to tailor reaction profile for desired open-time and fast post-curing	13
		Polyurethane surfactants	PU potting adhesive & froth foam	Optimize cell structure and foam stability	14
		Polyurethane dispersants and adhesion promotors	PU adhesive and sealants	Optimize material properties	
		Granules and heat stable binder	Fire-resistant and thermal insulation coatings	Coatings with excellent insulation and fire-resistant properties	15
Battery Cell	**Separator**	Fumed metal oxides (Al_2O_3)	Separator coating / incorporation	Improvement of thermal stability of separator	16-19
		Low foaming, wetting agent	Ceramic slurry	Ceramic slurry surface tension reduction	
	Electrolyte	Fumed metal oxides (Al_2O_3)	Gel / polymer electrolyte	Realize semi-solid electrolyte for safety improvement	
	Cathode	Fumed metal oxides (Al_2O_3, TiO_2)	Cathode Active Material (CAM) coating / doping	Protection of CAMs to enhance capacity retention / battery life	
		Dispersant	Cathode slurry	Slurry viscosity reduction and stability improvement	
		Flexing agent	Cathode	Increasing cathode electrode layer flexibility	
	Anode	Dispersant	Anode slurry	Slurry viscosity reduction and stability improvement	
		Flexing agent	Anode	Increasing anode electrode layer flexibility	
	Cathode / Separator	P84 PI as binder additive	Cathode additive / separator thermal stability	Increasing cathode adhesion strength / increase separator thermal stability	
Battery Management System	**Power Management and Connectivity**	PA12	Power busbars	For perfect electric insulation	20
	Protection and Thermal Management	PA12	Cooling and heating line and connectors	Excellence performance together with production efficiency, lightweight and competitive system cost	21
		Dielectric fluid	Immersive cooling	Efficient cooling performance that enables fast charging	22
		Fumed silica and metal oxides	Silicones, adhesives & sealants, and thermal insulation for EV LIB pack assembly	Functional additives to improve processibility, increase thermal conductivity and electrical insulation, improve long-term stability, and anti-settling as well rheology and reinforcement	23
		Silicone and filler treatment portfolio	Gap filler and thermal interface material	High flexibility of silicone formulation, improved thermal performance	24
Battery Recycling		H_2O_2	Recycling of Ni, Co, Mn, Li	As the reducing agent to recover Li, Co, Ni, Mn in the leaching process	25
Contact Us					26

EPOXY SMC BASED BATTERY ENCLOSURE

Battery Pack

VESTALITE® S curing agent is a high performance solution for sheet molding compound (SMC) material with low VOC when combined with a liquid epoxy resin.

Its unique properties make it suitable for automotive applications in large scale automated manufacturing (e.g. battery enclosure).

CONSORTIUM APPROACH

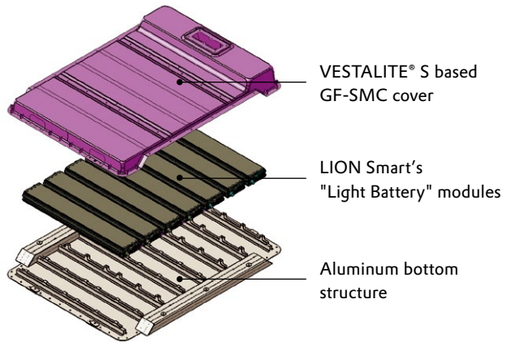
Joint development of Evonik's Joint Venture Vestaro and further partners including Forward Engineering, Lorenz, Lion Smart and Minth.

HARDWARE DEMONSTRATOR

Epoxy SMC based on VESTALITE® S enables easy processing as the material shows excellent mold flow combined with fast curing.

CONCEPT DEVELOPMENT

Multi-Material-Design to address all relevant functions and requirements of an integrated battery system.



More solutions available:
Structural adhesives for Electric & Electronics
Ancamine® cyclo-aliphatic amine and Ancamide® polyamide curing agents offer a wide product range to modify Tg, viscosity, latency, cure speed and toughness of 2K adhesives for ambient and heat cure applications for battery enclosures and structural applications in electric vehicles.

Crosslinkers

CONCEPT USPs & BENEFITS

Efficient material usage
- Complex geometric shape for part reduction and optimal system packaging
- Multi-material usage to address different requirements like fire resistance or EMC
- Best in class mechanical performance of EP-SMC and local reinforcement materials enables low battery weight

Functional integration
- Integration of module connection parts and further battery system relevant components (e.g. E / E-architecture)
- Integration of sealing and venting elements

Cost effective design and manufacturing
- Modularity of battery system sizes due to specific tooling concept and adjustable "Light Battery" module sizes
- Outstanding energy and power density at low costs

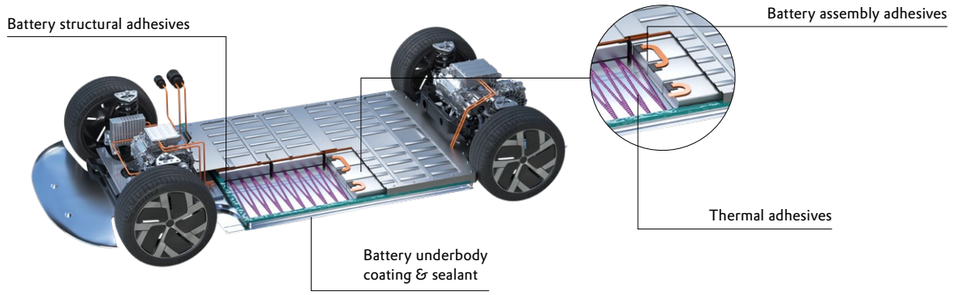
EPOXY CURING AGENT FOR **BATTERY ADHESIVES AND SEALANTS**

Battery Pack

ANCAMIDE® offers a range of polyamides and adducts to be used in EV battery adhesives with improved adhesion, lower viscosity and faster cure speed.

ANCAMINE® with modified aliphatic and cycloaliphatic curing agents provide various choices in EV battery adhesives, such as pot-life, viscosity, cure speed, and chemical resistance.

NOURYBOND® is the broadest range of high-performance adhesion promoters for automotive PVC and acrylic plastisols in the world. The Nourybond® polyamide-based and blocked isoyanate-based technologies provide solutions to the most demanding performance requirements.



Epoxy 2K curing agent

Product	Viscosity	AHEW	PHR	Gel Time	Features
ANCAMIDE® 910	6,000	230	110-125	120 min	• Outstanding flexibility and peel strength • Excellent thermal shock resistance • Better adhesion to a wide variety of substrates
ANCAMINE® 2842	2,800	230	123	17 min	• Lower viscosity and suitable for high filler content system • Fast curing speed • Excellent flexibility
ANCAMINE® 1922A	10	55	229	57 min	• Produces exceptional toughness, resiliency • Thermal shock resistance and outstanding impact resistance • Good electrical properties
ANCAMINE® 2914UF	300-2,000	95	50	8 min (20 g mix)	• Ultra-fast cure speed at room temperature • Excellent mechanical properties • Can be used as accelerator

Adhesion promoter in PVC plastisol

Product	Viscosity	Amine Value	Features
NOURYBOND® 382	15,000-25,000 (40 °C)	280-330	Promoting PVC plastisol adhesion even under lower baking temperature (130 °C) or shorter baking time (15 mins)

Viscosity: Brookfield RVTD, Spindle 4, mPa.s at 25 °C

PHR: With bisphenol-A based epoxy resin (EEW=190)

Gel Time: Techne GT-3 gel timer, 150 g mix at 25 °C (unless indicated otherwise)

Amine Value: Perchloric acid titration, mg KOH/g

APAO AND LIQUID RUBBER FOR **EV BATTERY ADHESIVES & SEALANTS**

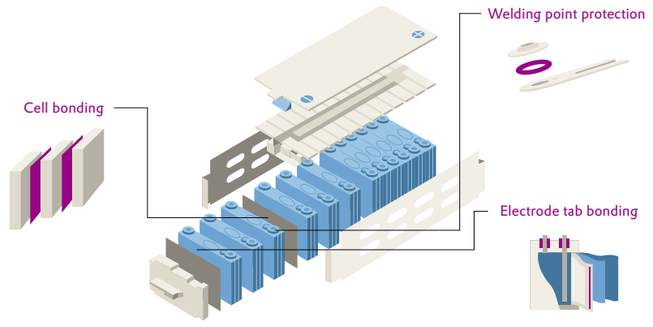
Battery Pack

VESTOPLAST® and POLYVEST® products are widely used as binders/additives for adhesives and sealants in battery cell and pack, enhancing the performance of lithium-ion batteries.

Product	Application
VESTOPLAST® series	Raw material with superior electrode resistance for hotmelt adhesive for cell structure bonding, welding point protection, electrode tab bonding etc
POLYVEST® HT, POLYVEST® HT LV, POLYVEST® MA series, POLYVEST® MAT, POLYVEST® ST-E 60	2K PU for gap filler or thermal conductive adhesive for EV-battery assembling

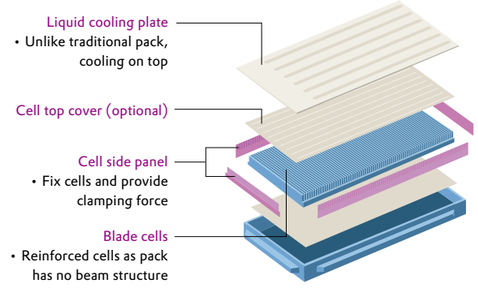
VESTOPLAST® are characterized by the following product properties and show great performance in EV battery system applications.

- Excellent electrolyte resistance
- High thermal stability
- Excellent adhesion and hot tack properties
- Very good hydrolytic and UV stability
- Bonding to various substrates, especially on PP without pretreatment



Due to its microstructure POLYVEST® grades are highly reactive crosslinking binders or used as additives providing properties including:

- Low viscosity
- Adjusted thixotropy
- Excellent chemical resistance to acids and bases
- High water resistance
- Low moisture and oxygen permeability
- Good flexibility



DYNASYLAN® ORGANOFUNCTIONAL SILANES AS **ADHESION PROMOTERS**

Battery Pack

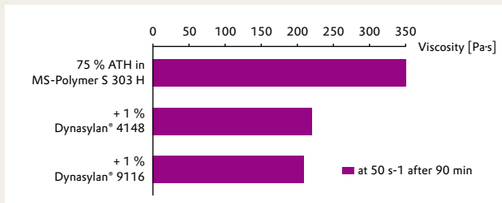
Dynasylan® organofunctional silanes act as adhesion promoters in various EV battery adhesives and sealants. In addition, special Dynasylan® grades can help to adjust the filler loading and rheological properties.

Adhesion promoter in various polymer systems

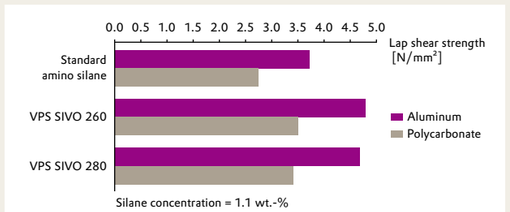
Product	Characteristics	Application
Dynasylan® 1124	Secondary aminosilane	High crosslinking potential for 2K PU, 2K EP, SMP and special primers
Dynasylan® 1146	Oligomeric aminosilane	Suitable for 2K PU, 2K EP, SMP, imparting outstanding hydrophobicity and reduced VOC
VPS® SIVO 260	Oligomeric aminosilane	Excellent adhesion on substrates and recommended for 2K PU, 2K EP, SMP
VPS® SIVO 280	Oligomeric aminosilane	
VPS® 4721	Oligomeric epoxysilane	Suitable for PU, EP, and various other polymer systems
VPS® 7163	Isocyanurate silane	High crosslinking potential for PU, EP and other polymer systems
Dynasylan® 9116	Alkyl silane	Able to adjust the filler loading and rheological properties
Dynasylan® 4148	Polyether silane	

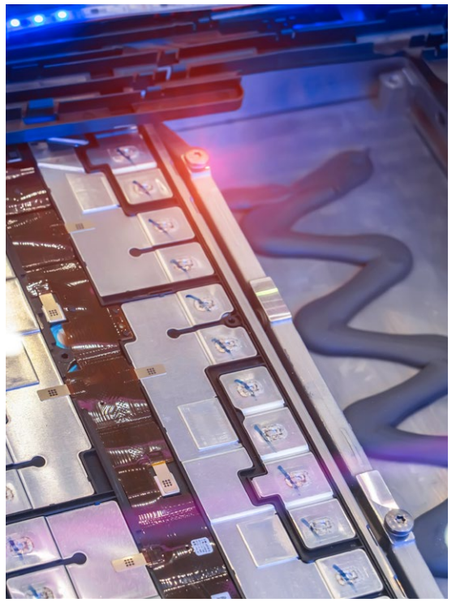
* PU = polyurethane systems, EP = epoxy systems, SMP = silane modified polymer systems

Improve the filler loading and systems workability by reducing the viscosity at higher shear rates



Enhance the primerless adhesion on aluminum and polycarbonate in STPU systems





POLYCAT® SA, KOSMOS® & DABCO® SERIES FOR **THERMAL CONDUCTIVE / STRUCTURAL ADHESIVE**

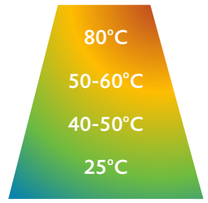
Battery Pack

- Tailor curing profile for optimizing your process and formulation
- Enable a process transfer to automated production Improvement of aging stability

Recommended product series

Products	Description
POLYCAT® SA series	• Thermolatent amine catalysts • Suitable for aromatic system • Balancing pot-life and through cure
KOSMOS®, DABCO® series	• Delayed tin catalysts • Suitable for aromatic and aliphatic system • Balancing pot-life and through cure

Activation Temperatures of Thermolatent Amine Catalysts



POLYCAT SA 8

POLYCAT SA 101/ 102

POLYCAT SA 1 /2 LE

POLYCAT SA 5

ORTEGOL® DA SERIES FOR **THERMAL CONDUCTIVE / STRUCTURAL ADHESIVE**

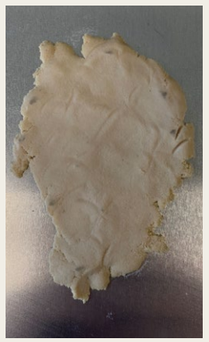
- Reduce system viscosity to optimize the process
- Enabling higher filler loading to meet the higher thermal conductivity targets
- Helps to maximize thermal conductivity

Recommended product series

Products	Description
ORTEGOL® DA series	• Suitable for formulations with >80% filler content • Compatible in both, polyol and isocyanate

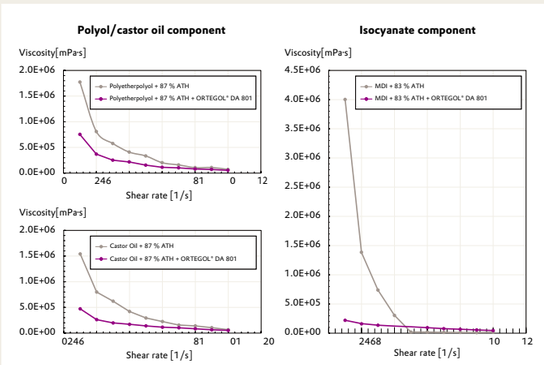
Conducive to efficient and uniform sizing

No dispersant



ORTEGOL® DA 801

Efficient performance in reducing viscosity

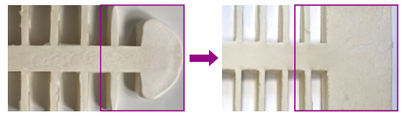


DABCO®, KOSMOS® & TEGOSTAB® B SERIES FOR **POTTING FOAM**

Battery Pack

- Enable optimal flowability for perfect filling distribution
- Ensure low foam temperature Improve adhesion to cells

Efficient flowability to help fill individual slits in complex molds



Traditional solution — Evonik's solution

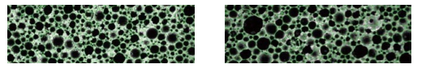
Recommended product series

Product	Types	Description
DABCO® series	Catalyst	Delay amine catalyst for excellent system flowability
KOSMOS® series	Catalyst	Delay tin catalyst, excellent back-end cure performance
TEGOSTAB® B series	Surfactant	Ideal foam stabilization and flowability
Adhesion promoter	Performance additives	Specialty additives to improve the adhesion to the metal surface of the cylindrical cells

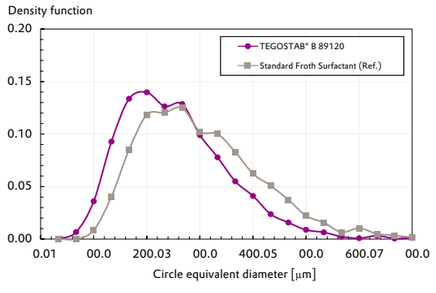
TEGOSTAB® B, KOSMOS® & POLYCAT® SA SERIES FOR **FROTH FOAM**

- Ensure wet froth stability and fine cell retention in drying process
- Low VOC options
- Co-surfactant options for flexibility formulation
- Low toxicity catalyst with ideal processing
- Possibility to reduce density

Evonik solution can help to improve the finesse and uniformity



TEGOSTAB® B 89120 — Standard Froth Surfactant



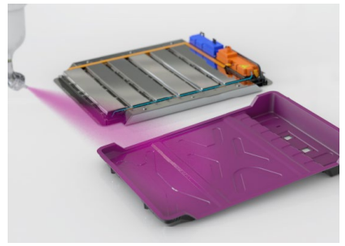
Recommended product series

Product	Types	Description
TEGOSTAB® B series	Surfactant	Silicone surfactants for foam stabilization and cell regulation
KOSMOS® series	Catalyst	Metal catalysts provide long operation time and good curing
POLYCAT® SA series	Catalyst	Amine catalysts provide thermo-activate behavior, improve processing latitude with long pot-life and fast curing

HEAT PROTECTION AND FIRE-RESISTANT COATINGS **THERMAL INSULATION GRANULES AND HEAT-STABLE SILICONE HYBRID BINDER FOR FIRE-RESISTANT COATINGS FOR EV BATTERY HOUSINGS & COVERS**

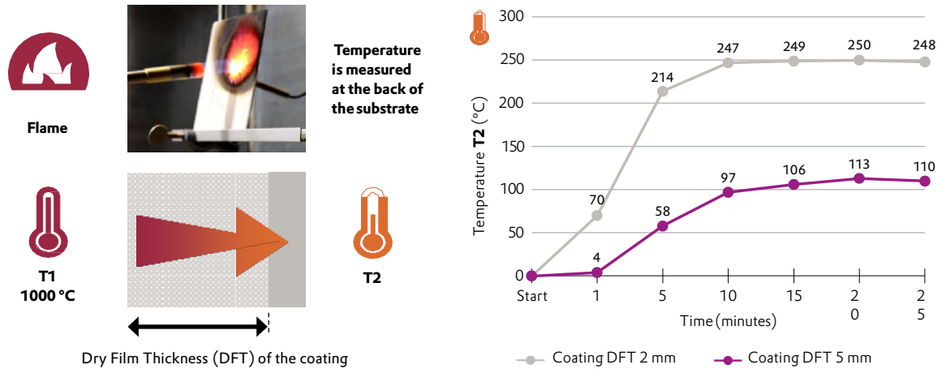
Battery Pack

The use of thermal insulation barriers in lithium-ion batteries is to mitigate the risk of fires resulting from infrequent but hazardous thermal runaway incidents in EV batteries. Fire-resistant coatings applied to battery covers represent one approach to reduce the risk of thermal runaway incidents. The TEGO® Therm product line facilitates tailor-made raw materials to formulate sprayable coatings that provide excellent fire resistance and thermal insulation characteristics. The combined use of microporous silica-based TEGO® Therm HPG granules and the heat-stable TEGO® Therm L300 binder allows to formulate flame-retardant coatings that meet the UL 94 V-0 fire safety standards.



Coatings formulated with TEGO® Therm effectively minimize heat transfer to the underlying substrate while preserving superior mechanical integrity during direct jetflame testing.

Fire Resistance Test – 20 minutes exposure to a 1000 °C jetflame



Coatings based on **TEGO® Therm L 300** binder combined with **TEGO® Therm HPG** granules can reach a thermal conductivity (λ value) of less than 40 mW/(m K). Thin coatings with a dry film thickness (DFT) of only a few millimeters, suitable for applications with limited space, enable effective insulation and protection of the substrate. Even with a flame temperature of >1000 °C, the temperature on the backside peaked at <250 °C.

TEGO® Therm portfolio – At a Glance

TEGO® Therm L 300

- Liquid waterborne polysiloxane hybrid binder with solid content ~50%
- Superior heat stability
- Low smoke and odor development

TEGO® Therm HPG 4000

- Granules with superinsulation properties from passivated amorphous SiO_2 core
- High hydrophobicity
- Non-combustible / Non-flammable

TEGO® Therm HPG 6806

- Granules with excellent insulation properties from amorphous SiO_2 core
- Small particle size enable smooth coating surfaces
- Excellent dimensional stability

AEROXIDE® FUMED METAL OXIDES AS **PERFORMANCE ADDITIVES**

Battery Cell

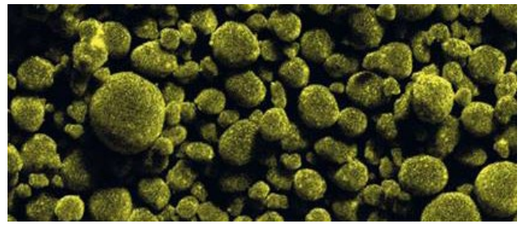
AEROXIDE® fumed metal oxides are produced by flame hydrolysis (AEROSIL® process), the loose white powder consists of nano-structured aggregates. AEROXIDE® metal oxides are used as additives in Li-ion batteries to increase the **performance, life-time** and **safety** of the battery.

Product	Application
AEROXIDE® Alu 130, AEROXIDE® TiO_2 P 25	Protective dry coating for cathode active materials
AEROXIDE® Alu 45, AEROXIDE® Alu C 805 **AERODISP® Ready to use dispersions**	High performance LIB separator as coating or filler
VP AEROXIDE® Alu C 711	Functional additive in new electrolyte formulations

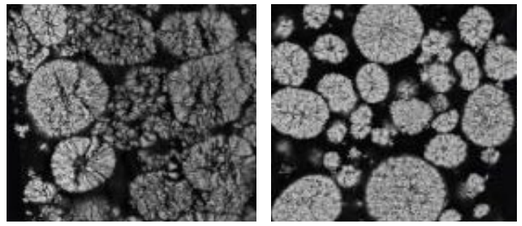
Dry coating for cathode active materials

AEROXIDE® is used for cathode material surface coating to stabilize cathode active material particles and to avoid cracks during charge/discharge, resulting in an increased capacity retention and enhanced battery life.

SEM: Al mapping of AEROXIDE® coated NMC particles

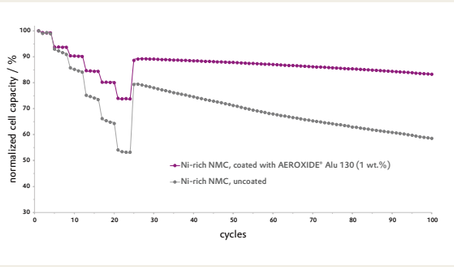


Cross section SEM imaging of cycled electrodes after 250 cycles



Ni-rich NMC, uncoated

Ni-rich NMC, **AEROXIDE®** coated



Example for stabilization of Ni-rich NMC.

Left
Powder mixture **before** dry coating process:
Uncoated cathode powder
+1 wt.-% AEROXIDE® Alu 130

Right
Final product **after** dry coating process:
1 wt.-% AEROXIDE® Alu 130 coated on cathode powder

AEROXIDE® fumed metal oxides (Al_2O_3 and / or TiO_2) as **dry coating** on cathode particles leads to a significant increase in rate capability and capacity retention of LIB cells.

Preferred AEROXIDE® products:

- **AEROXIDE® Alu 130**
- **AEROXIDE® TiO_2 P 25**

} Mixture of both oxides is beneficial

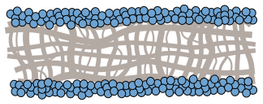
High performance LIB separator as coating or filler

AEROXIDE® fumed alumina enables the use of ultra-thin (≤ 1 µm), homogeneous ceramic coatings or is applied as ceramic filler inside the membrane, resulting in improvement of thermal stability of separator.

Battery Cell

Evonik also offers AERODISP® – Ready to use alumina dispersions, tailor made for specific coating application and compatible with a variety of different binders.

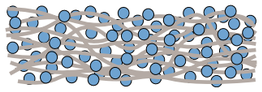
Particle coated



Ceramic particles on top of the microporous membrane

AEROXIDE®
AERODISP®

Particle incorporated

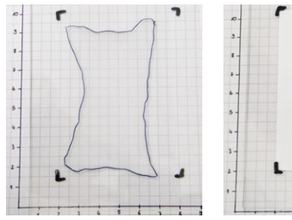


Ceramic particles throughout the whole interior of a polymer matrix

AEROXIDE®

Coating on separator

A thin ceramic coating made of AEROXIDE® fumed alumina strongly reduces the thermal shrinkage of separator and thus leads to an increased cell safety.



Uncoated separator at 150 °C

AEROXIDE® coated at 150 °C

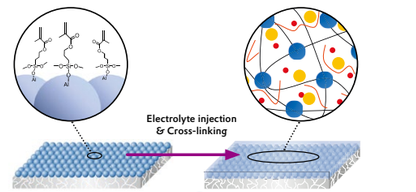
Ceramic filler inside separator

AEROXIDE® fumed alumina can also be used as ceramic filler inside separators, leading to excellent mechanical and thermal membrane properties combined with a high porosity.

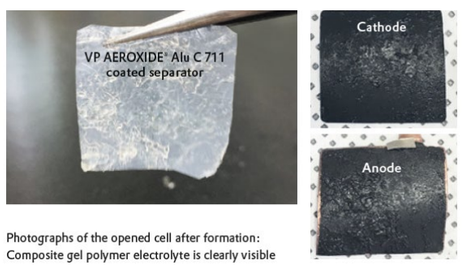
Example: Manufacturing of an AEROXIDE® filled separator

Functional separator coating: Formation of gel polymer electrolyte

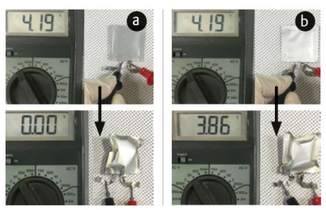
VP AEROXIDE® Alu C 711, a specially designed surface modified fumed alumina, is applied as thin ceramic coating on top of separators, to be triggered a cross-liking reaction with tetra (ethylene glycol) diacrylate (TTEGDA) additive in electrolyte to form electrolyte gelling. The formed gel polymer electrolyte with 3-dimensional network strongly enhances the contact between separator and electrodes.



TTEGDA = tetra (ethylene glycol) diacrylate



Photographs of the opened cell after formation: Composite gel polymer electrolyte is clearly visible



Photographs show the open-circuit voltage of cells assembled with (a) pristine PE separator + liquid electrolyte and (b) VP AEROXIDE® Alu C 711 coated separator + gel polymer electrolyte, measured before and after thermal exposure at 200 °C for1 h.

Detailed information available: https://doi.org/10.1016/j.jpowsour.2020.228519

TEGO® SURTEN E AS PROCESS ENABLER FOR **LIB ELECTRODE AND SEPARATOR MANUFACTURING**

Battery Cell

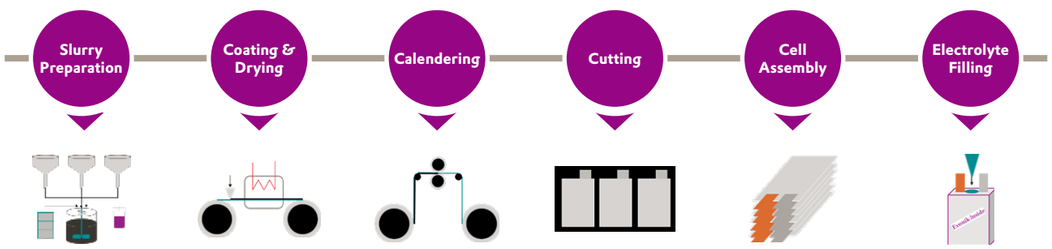
TEGO® Surten E series are the process enablers which help contribute to further improvements in the production of LIB's which yield better electrical performance and lower overall costs. Evonik broad surfactant technology platform allow us to offer a wide range of products from wetting and dispersing agents to defoamers as well as flexing agents.

- NMP based dispersant for cathode
- Water based dispersant for anode, separator
- Evonik provides broad wetting technologies
- Evonik provides all types of antifoam

Product	Application
TEGO® Surten 400 E series dispersant	Cathode slurry, slurry viscosity reduction, uniform distribution of active materials Cathode slurry, viscosity reduction and uniform distribution of conductive materials
TEGO® Surten 800 E series flexing agent	Electrode, improve electrode layer flexibility and reduce electrode layer cracking
TEGO® Surten 200 E series low foaming, wetting agent	Separator, surface tension reduction for ceramic slurry

Applications and key benefits

Separator coating	Wetting agent to ensure uniform coating and adhesive promo
Anode coating	Dispersant for slurry viscosity and grinding time reduction and uniform coating
Cathode coating	Dispersant for slurry viscosity reduction and uniform coating; flexing agent as anti-crack and swelling prevention
Electrolyte fillers	Liquid dispersant for next generation solid state electrolyte system
Calendering	Defoamers to help avoid foaming and air-entrapment



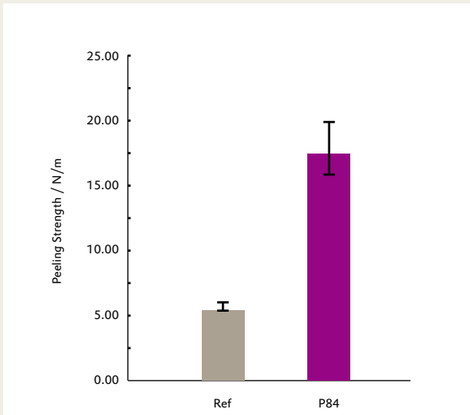
POLYIMIDE P84® AS ELECTRODES **BINDER / DISPERSANT BI-FUNCTIONAL ADDITIVES**

Battery Cell

The effective dispersion of the electrode active materials, and the adhision of the slurry and current collector are very important for the performance of lithium-ion-batteries.

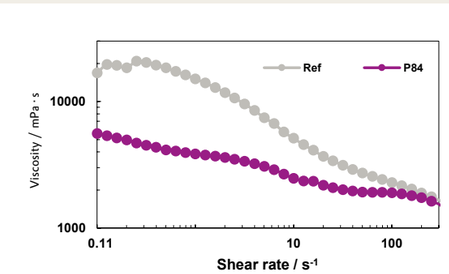
Polyimide P84® can not only disperse the actively materials and conductive materials effectively, but also improve the bonding strength, providing dual effects.

Average peeling strength of electrode with different additives



Sample	Ref-blank	P84
Peeling Strength (N/m)	5.73 ± 0.23	17.81 ± 1.60

The viscosity of LFP slurry with different dispersant



Shear rate (s^{-1})	Ref (mPa · s)	P84 (mPa · s)
0.1	16846	5595.9
1	15115	3845.9
10	5125.4	2465.2
100	2285.8	1899.5

The average peeling strength increase from 5.7 to 17.8 N/m by adding 3 wt% of polyimide P84 solution.

Polyimide P84 solution decreases the viscosity of electrode slurry by 66.8%.

INSULATION FOR HIGH VOLTAGE POWER BUSBARS WITH **VESTAMID®** **POLYAMIDE 12**

Battery Management System

Efficient management of electric power and permanently effective insulation of electrical components are key elements in e-mobility. The challenges include management of high voltage, high temperatures, and fire protection.

For more vehicle saftey, a high level of fire protection is expected of the plastics. Basically, the Evonik PA12 insulative materials provide outstanding and constant dielectric properties over the entire vehicle lifetime. This applies to power busbars in the high voltage bordnet, at HV charging and in particular, in high-voltage batteries. Powerbusbars are preferably insulated with polyamide 12 (PA12).

Evonik VESTAMID® PA12 is available at UL fire protection levels and includes halogen-free variants in the portfolio. The PA12 materials are in durable RAL signal color.

Evonik assists customers from setting up parameters for PA12 busbar co-extrusion to the bending of coated busbars and finishing of busbar components. In addition we support with specific polymer testing.

VESTAMID® for xEV power busbars

Properties	VESTAMID® PA12 compounds
Application voltage	High voltage up to 1000 V and more
Busbar metal core	Copper, aluminum, steel, … (also tin / nickel plated)
Coating material	PA12, various grades available, grades UL94 certified
Coating thickness	0.5 – 1 mm
Coating process	Co-extrusion, injection overmould
Color	Orange RAL 2003, RAL 2004, RAL 2008, natural
Flame resistance acc. UL 94 (IEC 60695-11-10)	V0, V2, HB
Halogen-free	Yes
Temperature resistance	Up to +125 °C
Volume resistivity (IEC 62631-3-1)	10^{13} Ωm
Electric strength (acc. to IEC 60243-2, ISO 6722 / 19642)	AC > 25 kV / mm, DC > 40 kV / mm
CTI (IEC 60112)	600

PA12 co-extrusion → **forming and finishing** → **polymer testing**

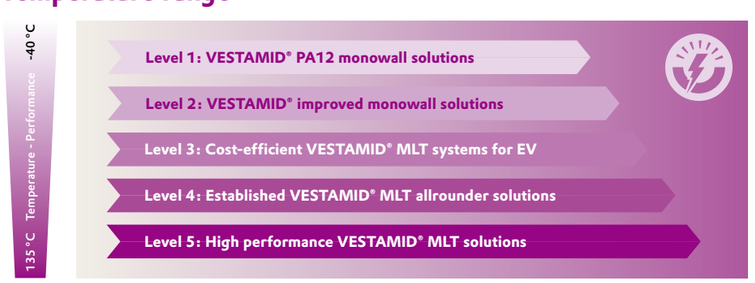
THERMAL MANAGEMENT WITH TUBING SYSTEMS FROM **VESTAMID®** **POLYAMIDE 12**

Battery Management System

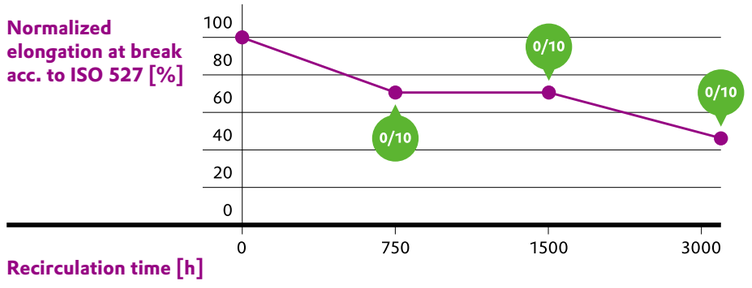
During the high power charging cycles, or while driving (battery discharging), or even while being parked, the temperature of EV battery can exceed the given limit. With lines made from VESTAMID® we provide the suitable solution for both, **water glycol** or **refrigerant** used in the cooling cycles, to enable an effective thermal management and keep the temperature in your car battery at the desired level.

The performance of EV batteries, electric motors, and other high power components benefits from our specialized **mono- and multilayer tubing systems** by keeping its temperatures within the required limits.

Temperature range



Level 3: VESTAMID MLT 8EV.1 for BEV-Recirculation at 110°C



- **MLT 8EV.1**

x / 10:
x of 10 specimen broken in cold impact test at -40°C (SAE 2260)

Specimen MLT:
ID 6mm / OD 8mm

Evonik cooling line solutions based on VESTAMID®

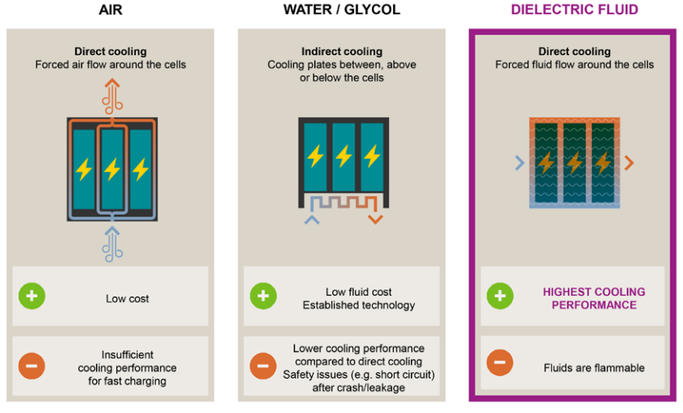
- Production efficient: Extrusion of MLT, thermoforming and insertion of quick connectors
- Lightweight: 30% to 50% weight reduction of complete system (MLT 8000 vs. AL / rubber)
- Performance: Excellent mechanical and chemical behavior as well as good anti-hydrolysis properties
- System material cost: Significant advantages compared to current concepts
- Packaging benefit: Less package space needed than for rubber hoses
- Excellent performance: Qualified for both, inside and outside battery pack application
- Proven: Serial use at OEMs globally

DIELECTRIC THERMAL MANAGEMENT FLUIDS FOR **EV APPLICATIONS**

Battery Management System

For the performance, durability and safe operation of a traction battery, it is essential to ensure operation in the optimal temperature range. This requires a powerful thermal management system, which can be achieved with submerging the battery cells in a dielectric fluid. Compared to air or water/glycol cooling systems cooling with dielectric fluids offers numerous design advantages.

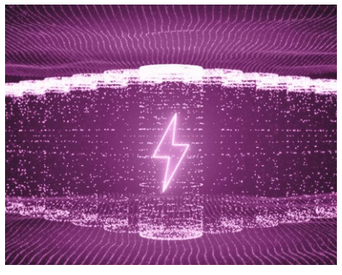
Product	Application
VISCOBASE® 11-416	Ultra-low viscosity synthetic hydrocarbon fluid that combines good heat capacity and thermal conductivity with very good material compatibility and superior low temperature flow performance
VISCOBASE® 11-150	Biodegradable low viscosity synthetic ester fluid that combines high heat capacity and thermal conductivity with low electrical conductivity and excellent low temperature performance.



Dielectric cooling allows

- Faster charging
- Prolonged battery life
- Electrical efficiency for increased vehicle range

	Unit @ 40 °C	VISCOBASE® 11-150	VISCOBASE® 11-416
Density	kg / l	0.88	0.78
Viscosity	mm^2 / s	4.3	4.1
Specific Heat	kJ / (kg·K)	1.9	1.9
Thermal Conductivity	mW / (m·K)	137	123
Electrical Conductivity	nS / m @ 25 °C	0.01	0.20



FUMED OXIDES FOR BATTERY ADHESIVES & SEALANTS, SILICONES, AND THERMAL INSULATION **AS WELL EXCELLENT RHEOLOGY AND REINFORCEMENT**

Battery Management System

Products	Features	Requirements
AEROSIL® R 202 / R 208 / R 805	Structural adhesives	Thickening thixotropy, and reinforcement
AEROXIDE® Alu 45 / 65 / 130 **AEROXIDE® Alu C 805** **AEROSIL® R 711**	Thermal conductivity	Rheology control
AEROXIDE® TiO_2 P 25 / PF2	Thermal stability	Silicone degradation at high temperatures, e.g. in silicone cables, sealants, and gaskets
AEROSIL® 200 / 300 / 380	Thermal insulation	Cost-effective inorganic fillers Highly porous inorganic fillers
AEROSIL® R 104 / R 106 (D4 treated)	Low volatiles	Safe usability on production lines

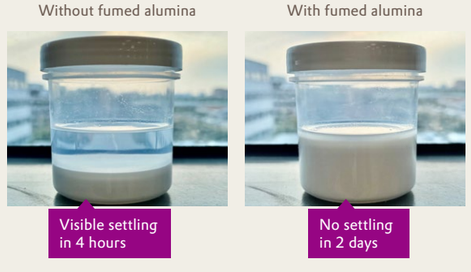
Additives for highly filled thermally conductive formulations

- Anti-settling for micron sized spherical alumina
- Lower viscosity for boron nitride filler
- Improved thermal conductivity in addition to the role as rheology modifier
- Reducing thickening, featuring with our low surface area fumed alumina e.g. AEROXIDE® Alu 45 and 65

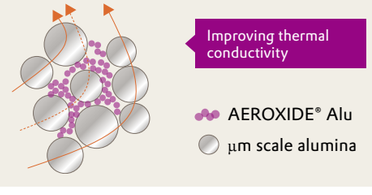
Additives for silicones

- AEROXIDE® TiO_2 PF 2 is a unique fine particle mixed oxide consisting of titania and iron oxide, manufactured analogous to the AEROSIL® process
- Hydrophobized silica such as AEROSIL® R 104 / AEROSIL® R 106 offers a safe production environment due to low content of D4 volatiles

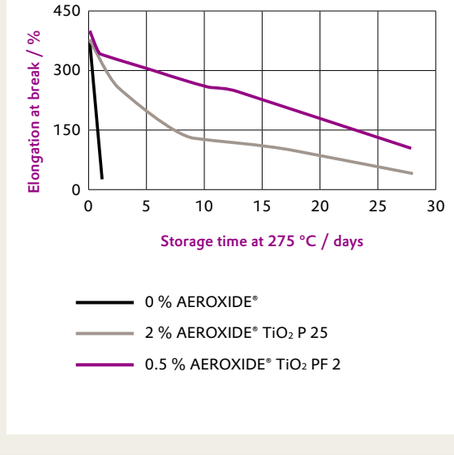
Anti-settling demonstration:
No visible settling of large particles after 2 days



Reference formulation: 60% 40 µm spherical aluminia, 2% AEROXIDE® Alu with Silicone VS 200



Elongation at break of silicone rubber at high temperature:
adding 1.0 – 3.0 wt.-% of AEROXIDE® TiO_2 P 25 or 0.25 – 1.0 wt.-% of AEROXIDE® TiO_2 PF 2 is an effective solution to improve the thermal stability of silicones



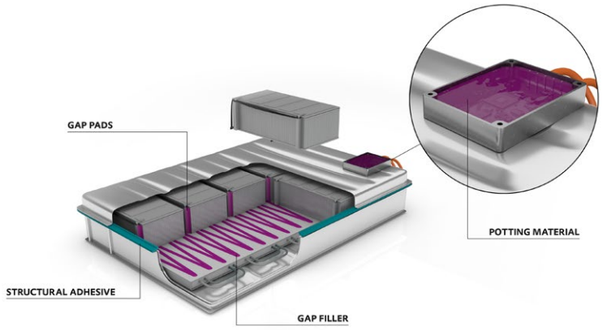
SILICONE AND FILLER TREATMENT PORTFOLIO FOR **BATTERY ASSEMBLY**

Battery Management System

Silicone portfolio

Product	Application
Polymer VS silicones	Vinyl-terminated silicone portfolio with broad range viscosity starting from 20 mPas
Crosslinkers	Full range with different SiH contents & viscosity
Modifier 700 series	Di-functional SiH structure to archive low process viscosity and high elongation properties
VQM 900 series	Vinyl-functional QM resin for high mechanical properties and transparent formulations
TEGOSIL® Heatban	Heat stabilizer to improve formulation heat resistance up to impressive 300 °C
TEGOSIL® FR 1000	Flame retardant co-compound for higher flame retardancy standard

Our full portfolio of silicone raw materials give high flexibility to build your formulation with desired viscosity, curing speed, hardness and high performance. Guiding formulations and technical exchange with our experts upon request.



Evonik solutions include:
Raw materials and additives for

- Gap fillers
- Thermal interface materials
- Battery assembly adhesives

Filler treatment portfolio for better thermal conductivity and flame retardancy

Product	Application
TEGOPREN® 6875 & 6879	Organo-modified siloxane chemistry for hydrophobic treatment of functional filler. Can also be used as in-situ dispersion additive
TEGOMER®	Broad chemical portfolio for filler treatment and in-situ additive in matrix

TEGOPREN® and TEGOMER® products enhance the functionality of different fillers in silicone, urethane, epoxy, acrylic and thermoplastics. Filler treatment benefits include:

- Improved filler distribution in the matrix leading to higher thermal conductivity, better flame retardancy and lighter weight
- Reduced formulation and processing viscosity and lower water uptake
- Further increase of functional filler dosing level which enables even higher performance

For other matrices, we also offer high performance raw materials including NANOPOX®, NANOCRYL®, ALBIFLEX®, ALBIDUR® for the flexibilisation and long-term performance of epoxy and acrylic.

LIB RECYCLING WITH HYDROGEN PEROXIDE AND PERSULFATE **ECO-FRIENDLY OXIDANTS**

Battery Recycling

Lithium-ion batteries (LiBs) are widely used in electric vehicles and smart portable devices. As more and more of these items reach the end of their life cycles, it is becoming increasingly critical to recycle the LiBs in order to reuse the rare and precious metals contained within them, such as lithium and cobalt. Hydrogen peroxide and persulfate are uniquely positioned to aide in the recovery of these metals during the LiB recycling process.

Product	Application
HYPROX® 350, HYPROX® 500	Recovery of Li, Co, Ni, Mn in the leaching processes
CLAMARIN® 350, CLAMARIN® 500	Wastewater treatment to breakdown organics to reduce COD
Ammonium persulfate and sodium persulfate	Oxidative leaching of oxidizable metals such as lithium

Application overview

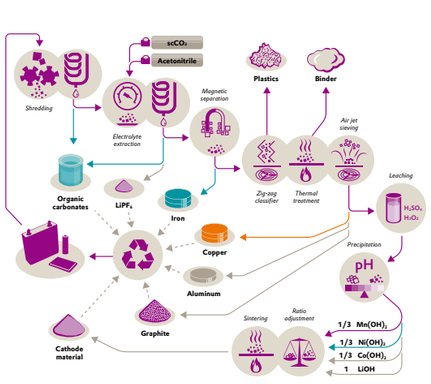
Hydrogen peroxide

Among the various LiB recycling technologies, one widely implemented process is called "wet hydrometallurgy". Here, hydrogen peroxide (H_2O_2) is used as a reduction agent in the leaching step to:

- Oxidize or reduce the metals such as Co, Mn, Ni, Li, and Fe to aide in their recovery from the LiB substrates;
- Increase leaching efficiency and shorten leaching time;
- Because hydrogen peroxide decomposes into only water and oxygen, it leaves minimal trace on the environment.

Hydrogen peroxide is also an effective and sustainable solution for wastewater treatment: It can be used alone or in combination with advanced oxidation process (AOP) technologies to break down organic chains to reduce the chemical oxygen demand of wastewater.

Process flow scheme of wet hydrometallurgy LiB recycling

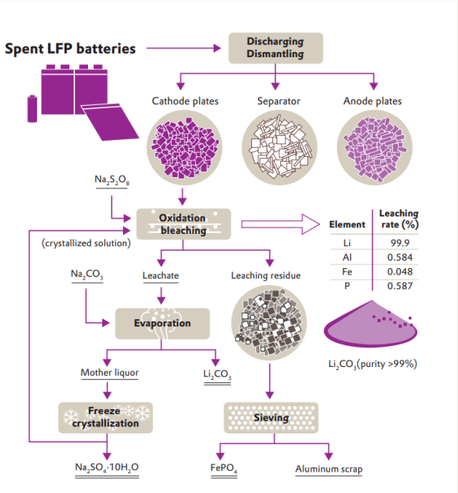


Persulfate

Persulfate is another peroxygen produced by Evonik. While hydrogen peroxide can either oxidize or reduce respective metals, persulfate provides a primarily oxidative pathway under conditions typically employed in LiB recycling. For example, this pathway is used as a highly efficient method to recover lithium from lithium iron phosphate (LFP) batteries.

Persulfate is available in several salts that are used in LiB recycling, including ammonium persulfate and sodium persulfate. The persulfate process leaches lithium quickly and efficiently from the cathode powder.

Recovering lithium from lithium iron phosphate (LFP) batteries



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