ARKEMA

Energy-Curable **Dielectric Coating** for The Battery Cell

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Energy-Curable Dielectric Coatings

→ Introduction to Arkema

→ UV curing technology for energy savings and performance

→ Test methods and essentials for dielectric properties

→ Optimal components for optimal chemical and electrical properties

→ A global network dedicated to UV specialties and the battery industry

Sartomer® business of ARKEMA: Who We Are

A global leader in Specialty Materials

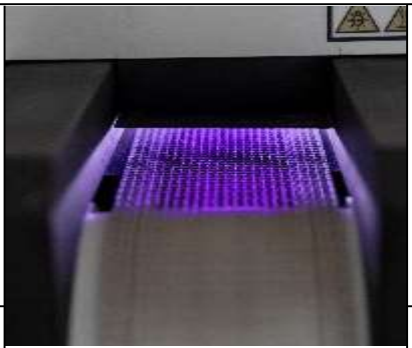
Arkema, through its **Sartomer Business Unit,** is a **pioneer in designing oligomer and monomer resins for radiation-curable manufacturing.**

Oligomers

High molecular weight compounds, backbone of the formulation, providing key functional properties

Monomers

Low molecular weight, low viscosity high performance reactive diluents, allowing viscosity control and optimization of the final properties



Photoinitiators

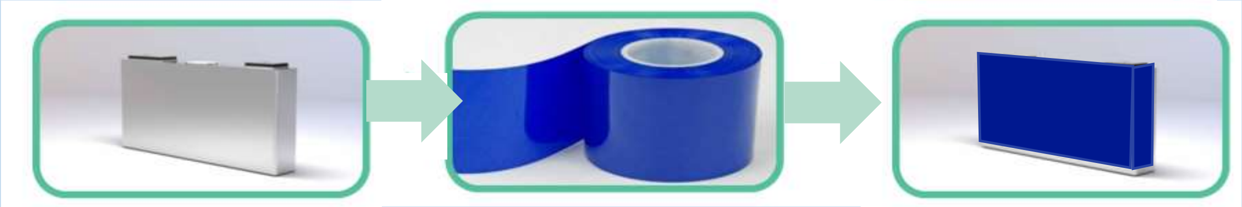
Initiate polymerization upon UV/LED light irradiation, synergists to enhance cure speed

Additives

Fine tune performance (e.g. storage stability, flow, adhesion, matting, weathering resistance...)

Processes of Dielectric Battery Coating

Conventional process
Tape



- ***Advantages:*** Cheap, mature
- ***Disadvantages:*** application complexity, bubbles, poor aging properties

New process
Powder coating

- ***Advantages:*** High efficiency, better process (Coating in the last step), better aging properties
- ***Disadvantages:*** long curing times, incomplete edge coverage

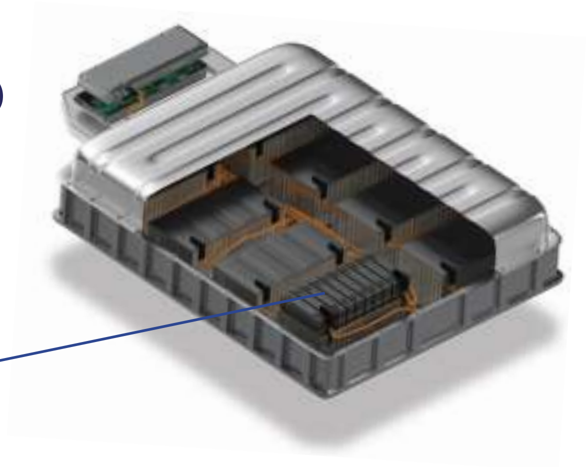
Our process: ***The UV curing advantage in battery manufacturing***

- No VOC 100% solids
- Low energy intensity
- Ambiant curing process
- Easier process
- High speed curing
- Dielectric resistance
- No film delamination

Sartomer® UV-Curable Dielectric Battery Coatings

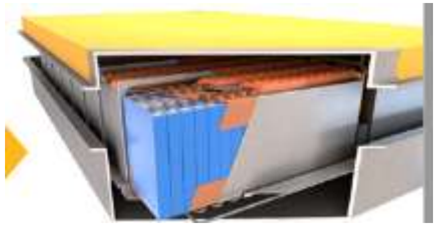
For outside the battery cells on electric vehicles

MODULE
(collection of cells)



ELECTRIC VEHICLE

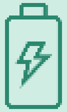
Dielectric UV Coatings for Battery Cells:
Provides electrical Insulation
Spray Applied



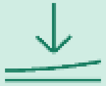
UV technology is emerging to replace tapes and powder coating with energy savings, performance and process improvement

Sartomer® components offer **optimal protection and insulation**

Instant drying



Excellent dielectric properties



Adhesion

Breakdown strength

Volume resistivity

Requirements For Dielectric Coating For Outside Of Battery Cell

Adhesion
- Aluminum substrate (Laser-treated and plasma-cleaned)
- Intercell adhesion

Dielectric properties
- Volume resistivity ASTM D257
- Dielectric breakdown ASTM D149

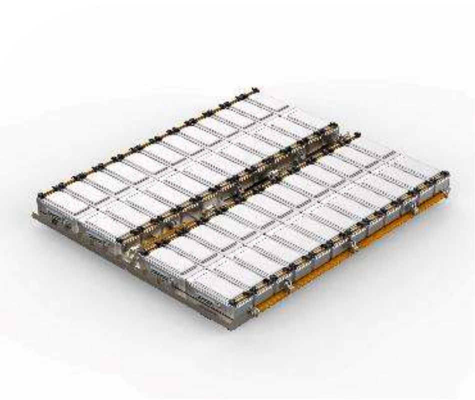
Ease of application
- Low applied viscosity

Aging tests
- High & low temperature impact
- Salt fog resistance
- Humidity resistance

Flame retardancy
- UL94v0

→ Application

- ➔ 100% solid content
- ➔ Hot Spray @ 40°C – 50°C
- ➔ Up to 130 µm layer thickness, in 2 coats
- ➔ Compatible with existing automated robots



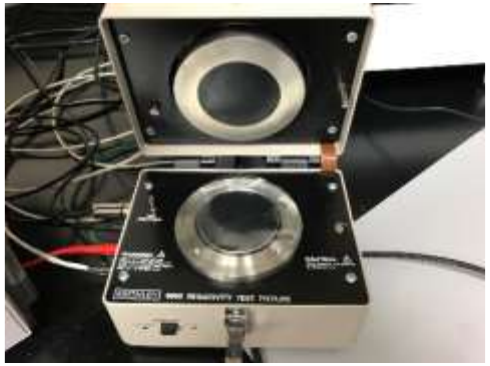
Key Property Requirement	Standard	Typical Target Value
Viscosity at 22°C, cPs	-	5,000-10,000
Pencil Hardness	ISO 15184-1998	>B
Adhesion-Tape Test	ASTMD3359	5
Flexibility	IPC-TM-650 2.4.5.1	Passed > 9mm
Volume Resistivity	ASTM D257	>10^{11} Ω.cm
Dielectric Breakdown, AC	ASTM D149	>8 kV
Dielectric Voltage Withstand, DC	ASTM D149	>6 kV

In-house Capabilities To Measure Dielectric Properties

Surface/Volume Resistivity
ASTM D257

The resistance to leakage current through the body of an insulating material

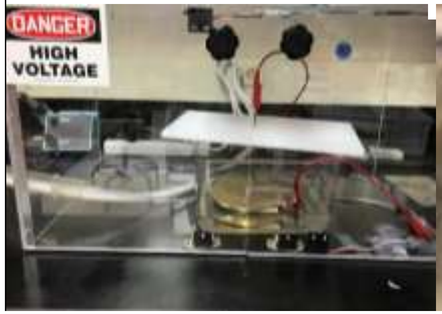
- ➔ Material is placed between 2 electrodes in the cell. The Megohmmeter is used to measure the resistance, at specific applied voltage
- ➔ Volume resistivity is calculated from measure resistance

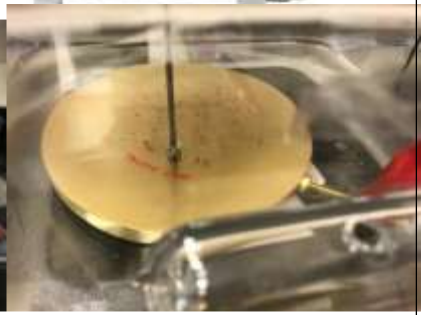


Dielectric Breakdown
ASTM D149

The failure of an insulating material under an externally applied field

- ➔ Voltage is applied across the two electrodes and raised from zero to dielectric breakdown at a uniform rate



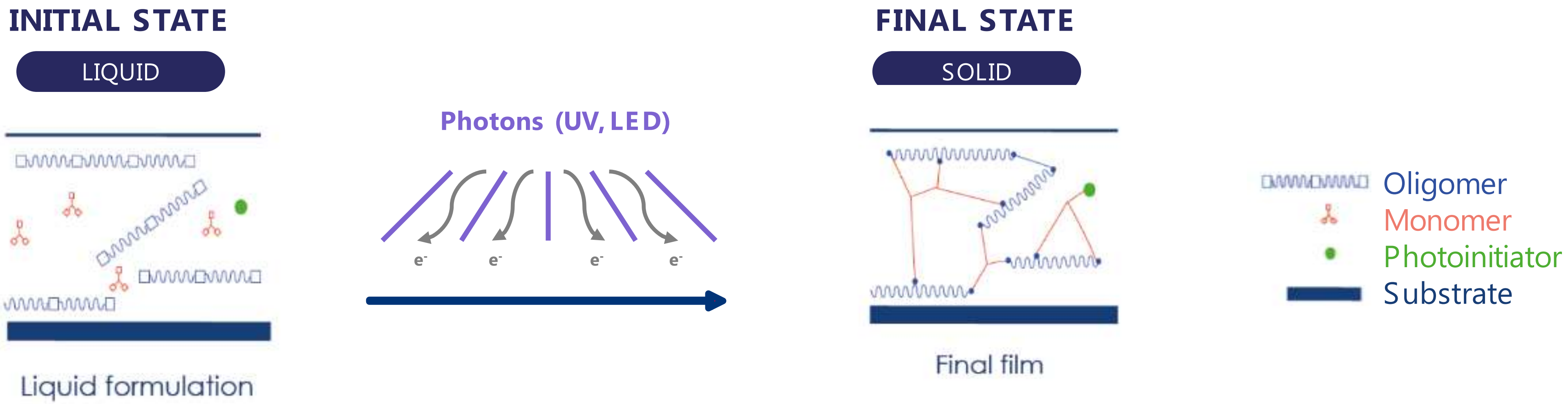


Dielectric Withstand
ASTM D149

The ability of an insulating material or device to withstand a high voltage without experiencing a disruptive electrical breakdown

- ➔ High voltage is applied to the insulating materials for a specified duration, and the current flowing through the materials is monitored

UV Curing, Coating, And Aging **Procedure**



* Photoinitiators

- Aluminum substrates are wiped with **toluene** in addition to **acetone** wipe
- Coatings are applied with **three different thicknesses**, including one 30µm layer, one 60µm layer, and 2x60µm layers of the resin on an Aluminum substrate using a drawdown bar
- Coated resin is cured using the **LED line** (395nm) and **fusion lamp** (H bulb)
- Coated specimens underwent aging in both an environmental chamber at **85°C/85%RH** and through **electrolyte soaking** for a duration of up to 4 weeks. Testing on these aged samples took place right after the aging tests. The coated specimens that had been immersed in electrolyte solvents were dried using cleanroom wipes and alcohol prior testing

Optimal Oligomers For **Mechanical And Dielectric** Properties

Polyester acrylate

Functionality	2
Viscosity @ 60°C	8800 mPa.s
Young Modulus	2 MPa
Elongation at break	90 %
Tensile Strength	1.9 MPa
Tg by DMA	10 °C

Adhesion

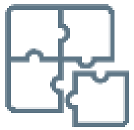
Polyester based Aliphatic Urethane DiAcrylate

Functionality	2
Viscosity @ 60°C	660 mPa.s
Young Modulus	134 MPa
Elongation at break	79 %
Tensile Strength	37 MPa
Tg by DMA	27 °C

Multi-purpose base oligomer

Polyether based Aliphatic Urethane DiAcrylate

Functionality	2
Viscosity @ 60°C	5900 mPa.s
Young Modulus	189 MPa
Elongation at break	137 %
Tensile Strength	21 MPa
Tg by DMA	8 °C



Compatibility with intercells adhesive system

PolyButadiene Based Urethane DiAcrylate

Functionality	2
Viscosity @ 60°C	5900 mPa.s
Young Modulus	189 MPa
Elongation at break	137 %
Tensile Strength	21 MPa
Tg by DMA	8 °C

Elastomeric behavior & shock resistance
Good insulation properties

Breakdown Strength	256 V/µm
Volume Resistivity	1,31e+15 Ω.cm

Performance of Optimal Oligomers in a Formulation

Polyester and Polyether diol-based aliphatic urethane acrylates offer a well-balanced combination of **adhesion** and **hardness**

Formulation: Optimal Acrylate Oligomer + Acrylate Monomer + Photoinitiator + Fillers/Additives

Film coated on Al substrate	Ave Volume Resistivity (Ω*cm) 500 V-60S	Standard Deviation (Ω*cm)	Adhesion	Hardness
Resin formulated with polyester-extended aliphatic UA				
30 µm - one layer	3.55E+13	1.40E+13	1	2H
60 µm - one layer	2.42E+13	1.05E+13	2	3H
60 µm - two layers	3.57E+13	3.60E+12	5	4H
Resin formulated with polyester diol-based aliphatic UA				
30 µm - one layer	1.84E+13	5.10E+12	3	4H
60 µm - one layer	2.05E+13	6.30E+12	5	4H
60 µm - two layers	2.13E+13	1.70E+13	5	5H
Resin formulated with polyether diol-based UA				
30 µm - one layer	1.36E+13	1.30E+12	5	3H
60 µm - one layer	9.43E+13	4.60E+13	5	5H
60 µm - two layers	8.76E+13	9.40E+12	5	5H

Aging Tests of Resin with **Polyether-Based Oligomer**

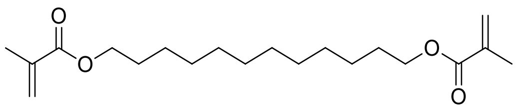
Polyether-diol based aliphatic UA exhibit strong **adhesion**, **hardness**, and **dielectric** properties subsequent to the 85°C/85%RH aging test

Formulation: Oligomer + Acrylate Monomer + Photoinitiator + Fillers/Additives

60um-one layer film coated on Al substrate	85°C/85RH				
	Initial	Week 1	Week 2	Week 3	Week 4
Viscosity @ 25°C cPs	2989				
Ave Volume Resistivity (Ω*cm) 500 V-60S	9.43E+13	9.00E+13	7.46E+13	5.80E+13	5.74E+13
Standard Deviation (Ω*cm)	4.60E+13	3.90E+13	2.50E+13	1.50E+13	3.70E+12
BDS V/um	174.44	161.94	160.58	157.23	151.32
Ave Adhesion (cross hatch)	5	5	5	5	5
Pencil Hardness	5H	5H	5H	5H	5H
Flexibility-Mandrel Bend Test 90° Diameter Range 4 - 34mm	Passed> 13mm	Passed> 13mm	Passed> 13mm	Passed> 13mm	Passed> 13mm

The Right Monomers With **Mechanical And Dielectric Properties**

1,12-Dodecanediol Dimethacrylate (DDDMA)



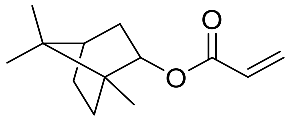
Functionality	2
Viscosity @ 20°C	12 mPa.s
Color	<200 Pt/Co
Tg by DCS	-37°C

Dielectric Properties

Breakdown Strength	482 V/µm
Volume Resistivity	4,53e+15 Ω.cm

Flexibility
Good water resistance

IsoBornyl Acrylate (IBOA)



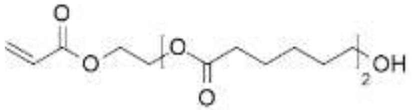
Functionality	1
Viscosity @ 20°C	8 mPa.s
Color	<50 Pt/Co
Tg by DCS	95 °C

Dielectric Properties

Breakdown Strength	384 V/µm
Volume Resistivity	1,08e+17 Ω.cm

Good hardness
Good adhesion to metal
High flexibility

Caprolactone Acrylate (CAPA)



Functionality	1
Viscosity @ 20°C	80 mPa.s
Color	<50 Pt/Co
Tg by DCS	-53 °C

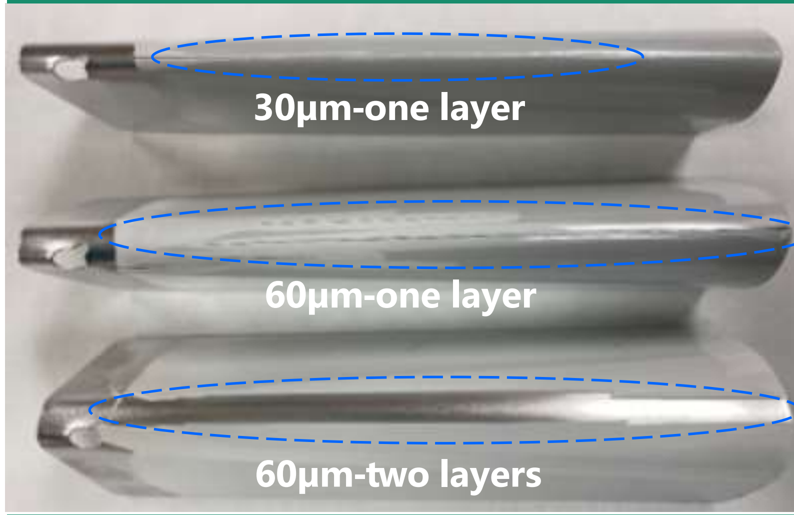
Good Flexibility
Good metal adhesion
Low shrinkage
Low odor

Flexibilizer - Performance of Monofunctional Diluents

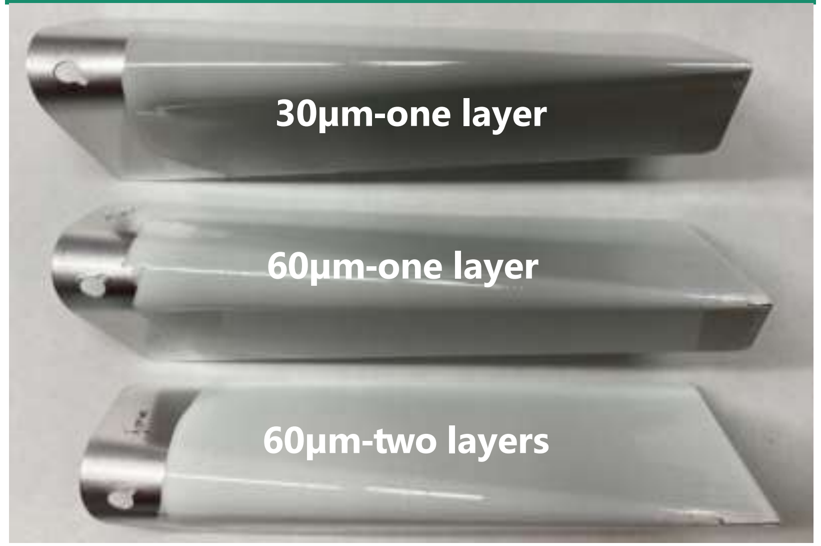
The addition of a flexibilizer to the resin enhances both **flexibility** and **adhesion** properties

Film coated on Al substrate	Ave Volume Resistivity (Ω*cm) 500 V-60S	Standard Deviation (Ω*cm)	Adhesion	Hardness	Flexibility Mandrel Bend Test 90° Diameter Range 4 - 34mm
Resin formulated without flexibilizer					
30 µm - one layer	1.47E+13	6.4E+12	2	3H	**Passed>18mm**
60 µm - one layer	2.60E+13	1.6E+13	4	4H	**Not passed**
60 µm - two layers	2.77E+13	1.7E+13	5	5H	**Not passed**
Resin formulated with flexibilizer					
30 µm - one layer	1.83E+13	7.3E+12	5	3H	**Passed**
60 µm - one layer	1.86E+13	8.3E+12	5	4H	**Passed**
60 µm - two layers	2.25E+13	9.3E+12	5	7H	**Passed**

Resin without Flexibilizer



Resin with Flexibilizer



Toughening Materials To Improve Flexibility And Hardness

TriCycloDecane Dimethanol DiAcrylate (TCDDMDA)

Appearance	Clear liquid
Functionality	2
Viscosity @ 25°C	130 mPa.s
Flexural Strength	45.16 MPa
Strain at Break	1.48 %
Energy at Break	0.10 J
Flexural Modulus	2876.90 Mpa
Hardness	89.3 D
Shelf Stability	>6 months

Toughened Version of TCDDMDA

Appearance	Clear liquid
Functionality	2
Viscosity @ 25°C	2,275 mPa.s
Flexural Strength	57.80 MPa
Strain at Break	4.20 %
Energy at Break	0.42 J
Flexural Modulus	1672.70 Mpa
Hardness	80.03 D
Shelf Stability	>6 months

Dielectric Properties

TCDDMDA:

Dk, 1kHz	3.329
Dk, 10GHz	2.771
Df, 1kHz	<0.0065
Df, 10 GHz	<0.01395
Surface Resistivity	>1.39E+16
Volume Resistivity	>1.17E+16

Toughened Version of TCDDMDA:

Dk, 1kHz	3.323
Dk, 10GHz	2.760
Df, 1kHz	<0.0089
Df, 10 GHz	<0.01410
Surface Resistivity	>1.53E+16
Volume Resistivity	>1.23E+16

Performance Data

Formulation: Resin + TCDDMDA/ Toughened Version + Fillers/Additives

60um-one layer film coated on Al substrate	TCDDMDA		Toughened Version of TCDDMDA	
	Initial	Electrolyte soaking 168 hr	Initial	Electrolyte soaking 168 hr
Viscosity @ 25°C cPs	1640.01		10510.90	
Ave Volume Resistivity (Ω*cm) 500 V-60S	7.39E+13	5.44E+13	5.19E+1 3	1.83E+1 3
Standard Deviation (Ω*cm)	9.30E+12	1.50E+13	1.50E+1 3	1.30E+1 3
BDS V/um	213.81	176.71	221.12	184.12
Ave Adhesion (cross hatch)	5	3	5	3
Pencil Hardness	4H	HB	5H	**2H**
Flexibility Mandrel Bend Test 90° Diameter Range 4 - 34mm	Not passed	Passed >6mm	**Passed >14mm**	Passed >4mm

➔ Key features of toughening version of TCDDMDA

- Promotes adhesion
- Good flexibility
- Good Hardness

Optimize Properties With **Phosphate Adhesion Promoters**

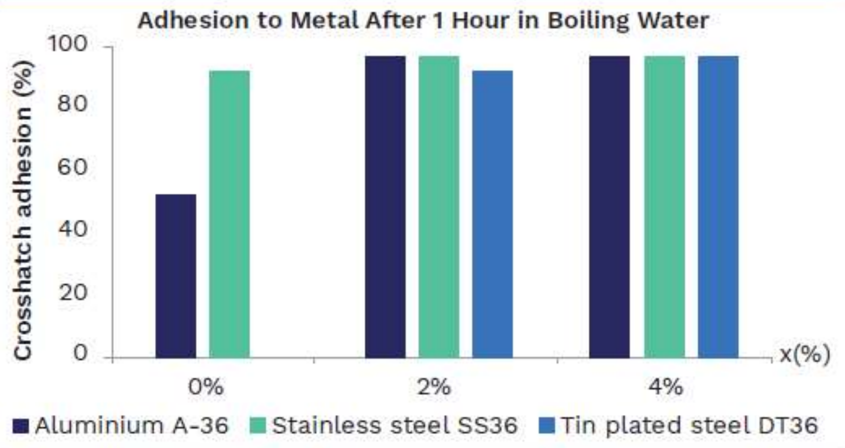
Acid Based Adhesion Promoter

Functionality	1-2
Viscosity @ 25°C	1600 mPa.s
Color	1 Gd
Acid value	280 mgKOH/g

Acid Ester Based Adhesion Promoter

Functionality	1-2
Viscosity @ 25°C	250 mPa.s
Color	5 Gd
Acid value	150 mgKOH/g

Acidic promoter into the resin



→ **Key features**

- Good Adhesion
- Good Chemical Resistance
- Good Hardness
- Good Water Resistance
- High Abrasion Resistance
- High Flexibility

→ **Cross hatch adhesion test**

Formulation without adhesion promotor after 2 weeks @ 85°C/85%RH

Formulation without adhesion promotor after 2 weeks @ 85°C/85%RH

Phosphate vs Non-Phosphate **Adhesion Promoters**

Formulation: Acrylate Oligomer + Acrylate Monomer + Adhesion Promoter + Photoinitiator + Fillers/Additives

Film coated on Al substrate	Ave Volume Resistivity (Ω*cm) 500 V-60S	Standard Deviation (Ω*cm)	Adhesion	Hardness
Resin formulated with phosphate acid based adhesion promoter				
30 µm - one layer	2.01E+13	1.5E+13	**5**	**2H**
60 µm - one layer	2.78E+13	8.2E+12	**5**	**5H**
60 µm - two layers	2.59E+13	1.5E+13	**5**	**7H**
Resin formulated with difunctional acid ester based adhesion promoter				
30 µm - one layer	1.90E+13	5.5E+12	**5**	**H**
60 µm - one layer	2.08E+13	3.6E+12	**5**	**2H**
60 µm - two layers	2.23E+13	9.9E+12	**5**	**3H**
Resin formulated with non-phosphate adhesion promoter				
30 µm - one layer	1.42E+13	2.3E+12	**0**	**HB**
60 µm - one layer	1.58E+13	7.0E+12	**0**	**HB**
60 µm - two layers	1.59E+13	4.2E+12	**0**	**F**

Aging Tests of Resin Formulated without **Adhesion Promoters**

Coated specimens with no adhesion promoters exhibited a **decline** in both **adhesion** and **hardness**, both prior to and following exposure to 85°C/85%RH and electrolyte soaking

Formulation: Acrylate Oligomer + Acrylate Monomer + Photoinitiator + Fillers/Additives

60μm-one layer film coated on Al substrate		85°C/85RH				Electrolyte Soaking 25°C			
	Initial	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4
Viscosity @ 25°C cPs	1985								
Ave Volume Resistivity (Ω*cm) 500 V-60S	6.84E+13	6.37E+13	5.87E+13	4.99E+13	4.37E+13	5.33E+13	4.07E+13	1.68E+13	1.33E+13
Standard Deviation (Ω*cm)	1.30E+12	1.10E+13	8.10E+12	3.30E+12	1.30E+13	1.70E+13	1.40E+13	5.70E+12	4.90E+12
BDS V/um	168.12	166.56	157.43	144.32	141.12	101.02	99.45	86.23	83.58
Ave Adhesion (cross hatch)	2	1	0	0	0	0	0	0	0
Pencil Hardness	F	HB	B	B	B	2B	2B	2B	2B
Flexibility-Mandrel Bend Test 90° Diameter Range 4 - 34mm	Passed> 28mm	Not Passed	Not Passed	Not Passed	Not Passed	Not Passed	Not Passed	Not Passed	Not Passed

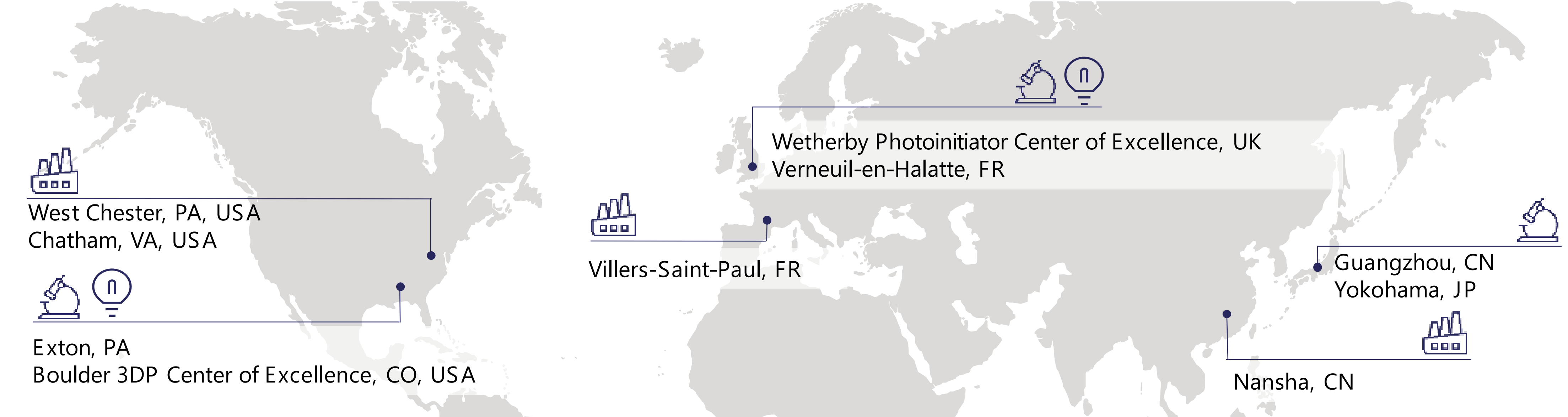
Aging Tests of Resin Formulated with **Adhesion Promoters**

Adhesion promoters enhance **adhesion** and **hardness** both before and after exposure to 85°C/85%RH and electrolyte soaking

Formulation: Acrylate Oligomer + Acrylate Monomer + Adhesion Promotor + Photoinitiator + Fillers/Additives

60µm-one layer film coated on Al substrate		85°C/85RH				Electrolyte Soaking 25°C			
	Initial	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4
Viscosity @ 25°C cPs	2567								
Ave Volume Resistivity (Ω*cm) 500 V-60S	8.08E+13	7.68E+13	7.61E+13	7.49E+13	7.58E+13	3.23E+13	2.62E+13	2.38E+13	1.96E+13
Standard Deviation (Ω*cm)	1.3E+13	1.3E+13	6.5E+13	6.7E+12	1.00E+13	4.6E+12	1.00E+13	8.70E+12	5.40E+12
BDS V/um	176.64	171.44	169.34	165.33	164.22	105.28	104.78	100.02	99.03
Ave Adhesion (cross hatch)	5	5	5	5	5	3	3	3	3
Pencil Hardness	8H	6H	6H	6H	3H	5H	5H	5H	5H
Flexibility-Mandrel Bend Test 90° Diameter Range 4 - 34mm	Passed> 20mm	Passed> 20mm	Passed> 22mm	Passed> 22mm	Passed> 22mm	Passed> 5mm	Passed> 5mm	Passed> 5mm	Passed> 5mm

Global Footprint Dedicated To UV Specialties And Battery Market



NA BATTERY APPLICATION LAB
Pouch cell assembly & cycling

CHRISTIAN COLLETTE EXCELLENCE CENTER FOR BATTERIES

ASIAN BATTERY TECH SUPPORT HUB
Lab for separator and cathode

Thank you!

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