⚡Staying Current:⚡ Everything You Need to Know About Electrical Properties for Plastic Design

BASF Performance Materials

BASF

We create chemistry

About the Presenters

Inga Balke

Senior Applications Development Engineer, BASF

Inga is a Senior Applications Development Engineer and has been working at BASF in the polymer industry for over 25 years. She has been focused on testing, agency requirements and design for the majority of her career. She has helped customers design with polymers in many different industries including electrical, HVAC, furniture, appliance, power tool and industrial applications. She attended Texas A&M University for both BS and MS mechanical engineering with a focus on mechanics of materials.

Dalia Naamani-Goldman

Market Segment Manager, Transportation, BASF

Dalia is the Electrical, Electronic, and e-Mobility Market Segment Manager with BASF's Performance Materials business where she is responsible for electric and autonomous vehicle materials and applications. Prior to BASF, Dalia worked for 5 years as a business consultant.

She received her B.S. from Northwestern University and MBA from University of Michigan.

Steve Losier

Market Segment Manager, Industrial E&E, BASF

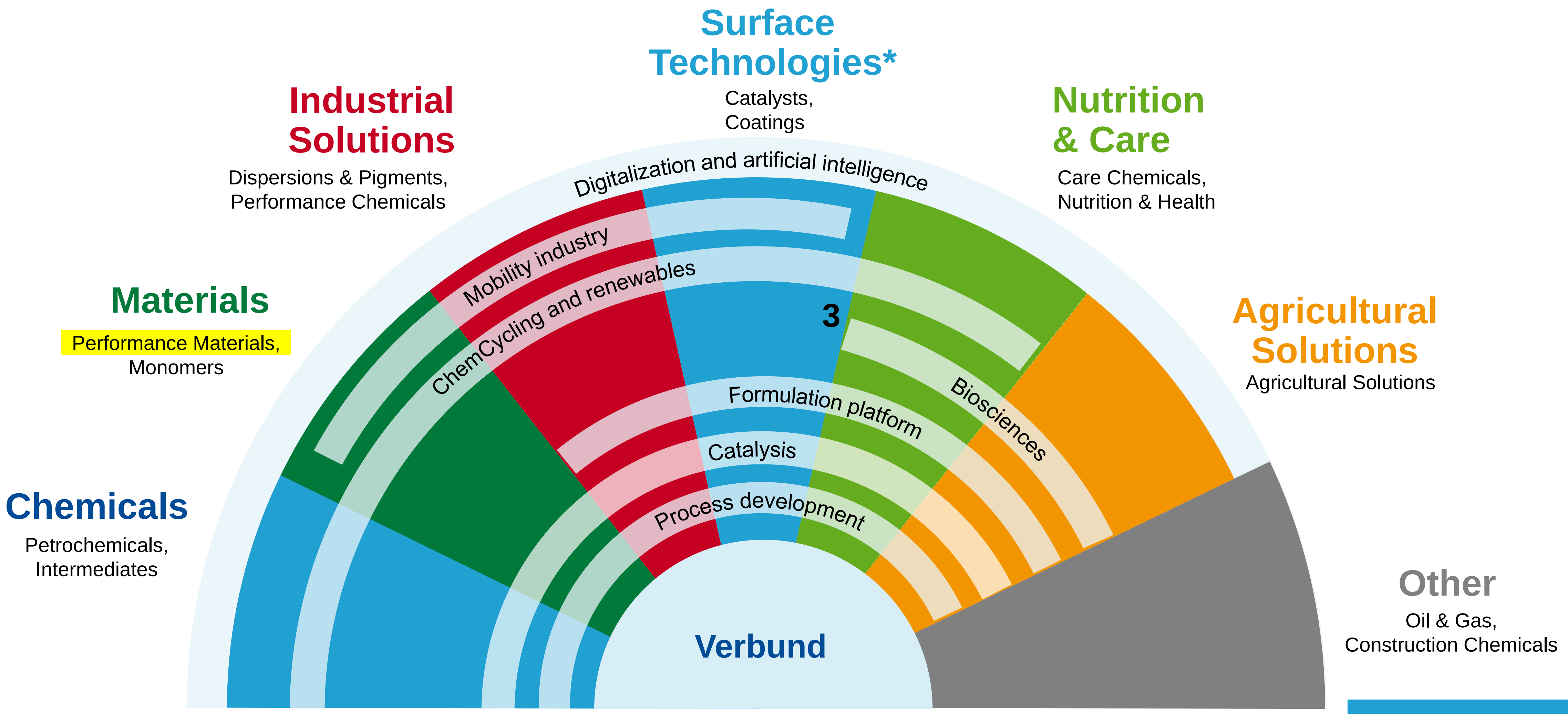
Steve is the Industrial Electrical and Electronic Market Segment Manager with BASF's Performance Materials business since August 2019. He has been with BASF for 6 years in Supply Chain and Product Management roles. Prior to BASF, he had 10 years in Supply Chain Management experience. Steve is currently supporting business growth in the Industrial E&E segment, through identifying market trends and coordinating development efforts.

He has a B.S. in Industrial Engineering from University of Windsor.

BASF
We create chemistry

BASF: We Create Chemistry for a Sustainable Future

BASF is the world's leading chemical company



BASF Performance Materials Product Portfolio

Polyurethanes

Cellasto®
Elastocoat®
Elastoflex®
Elastofoam®
Elastollan®
Elastolit®
Elastopan®
Elastopor®
Elastospray®
Elasturan®
Infinergy®
Slentex®

Engineering Plastics

Ultramid® PA6
Ultramid® PA66
Ultramid® PPA
Ultradur® PBT
Ultraform® POM

Specialty Plastics

ecovio®
ecoflex®
Basotect®
Ultrason® PES, PSU, PPSU
Palusol®
Neopolen®

AGENDA

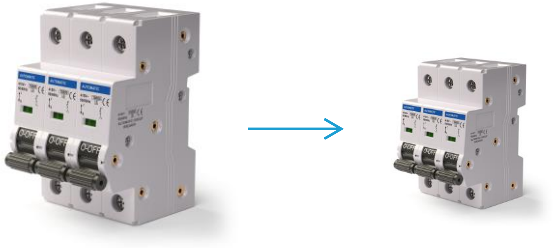
- Changing electrical landscape
- Flammability and resistance to ignition
- Insulation and isolation (resistivity, tracking, and creepage)
- Electrical durability and use (dielectric breakdown and relative permittivity)
- Resistance to heat aging

What Is Driving Interest in Electrical Properties of Polymers?

Electric Vehicles: Plastics are used as insulators, isolators and housings for components that carry current such as hybrid and battery electric vehicles, connectors, modules, circuit breakers, and switches

Autonomous Vehicles: Demands on the performance of the polymer keep increasing as new technology develops (relative permittivity is a major concern for autonomous systems)

Harsh Environments: Humidity, harsh chemicals, and high temperatures can change the behavior of polymers

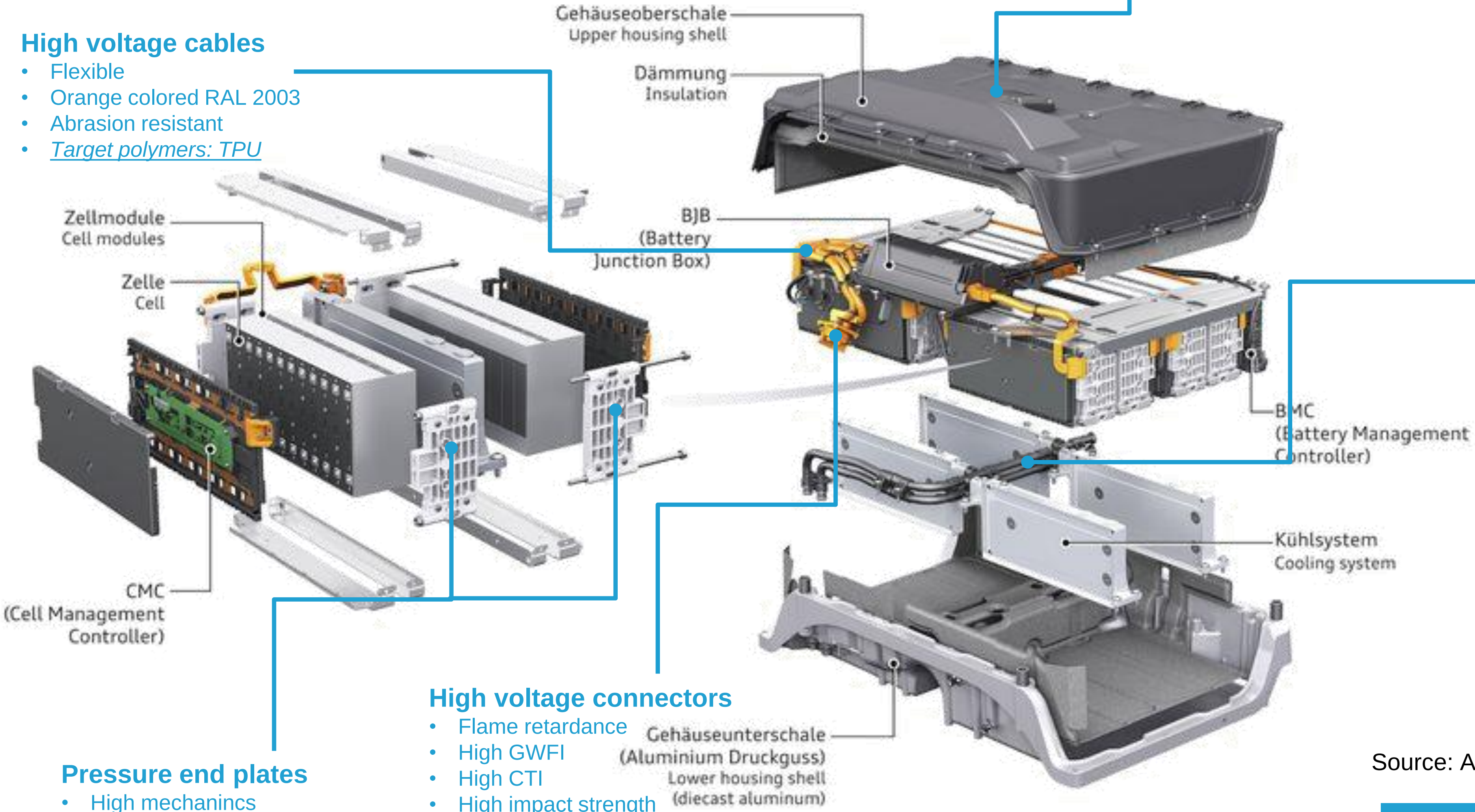


Miniaturization: Small electrical devices see greater heat rise; thin-walled parts pose manufacturing challenges

Critical Properties Vary By Application
Ex. Battery

Housing cover
- EMI shielding
- Flame retardance
- High mechanics
- *Target polymers: PA & PBT*

High voltage cables
- Flexible
- Orange colored RAL 2003
- Abrasion resistant
- *Target polymers: TPU*



Cooling pipes
- Hydrolysis resistance
- *Target polymers: PA*

High voltage connectors
- Flame retardance
- High GWFI
- High CTI
- High impact strength
- Orange colored RAL 2003
- *Target polymers: PA & PBT*

Pressure end plates
- High mechanincs
- Flame retardance
- *Target polymers: PA & PBT*

Source: Audi

BASF
We create chemistry

Decoding the UL Yellow Card

Ultradur® B4450 G5 HR (non-halogenated FR PBT)

PROSPECTOR®

CLICK TO CONTINUE

View additional material information including performance and processing data

The information presented on the UL Prospector datasheet was acquired by UL Prospector from the producer of the material. UL Prospector makes substantial efforts to assure the accuracy of this data. However, UL Prospector assumes no responsibility for the data values and strongly encourages that upon final material selection, data points are validated with the material supplier.

Component - Plastics E41871

Guide Information

BASF SE

Performance Materials Europe, E-PME/NQ - H201, Ludwigshafen 67056 DE

B4450 G5 HR (t)

Polybutylene Terephthalate (PBT) "Ultradur", furnished as pellets

Color	Min. Thk (mm)	Flame Class	HWI	HAI	RTI Elec	RTI Imp	RTI Str
ALL	0.40	V-2	1	0	75	75	75
	0.75	V-2	1	0	140	140	140
	1.5	V-0	1	0	140	140	140
	2.0	V-0, 5VA	1	0	140	140	140
	3.0	V-0, 5VA	0	0	140	140	140

Comparative Tracking Index (CTI): 0

Dielectric Strength (kV/mm): 26

High-Voltage Arc Tracking Rate (HVTR): 0

Dimensional Stability (%): -

Inclined Plane Tracking (IPT) kV: 1

Volume Resistivity (10^X ohm-cm): -

High Volt, Low Current Arc Resis (D495): 5

(t) - May be followed by the letters LS and a color code indicating laser sensitive coloring.

ANSI/UL 94 small-scale test data does not pertain to building materials, furnishings and related contents. ANSI/UL 94 small-scale test data is intended solely for determining the flammability of plastic materials used in the components and parts of end-product devices and appliances, where the acceptability of the combination is determined by UL.

Report Date: 2002-04-11

Last Revised: 2019-05-13

c UL US

BASF

We create chemistry

Flammability

Basic material response to thermal and electrical sources of combustion

Why It Matters

Not all materials behave in the same way depending on additives and responses to combustion (i.e. self-extinguishing)

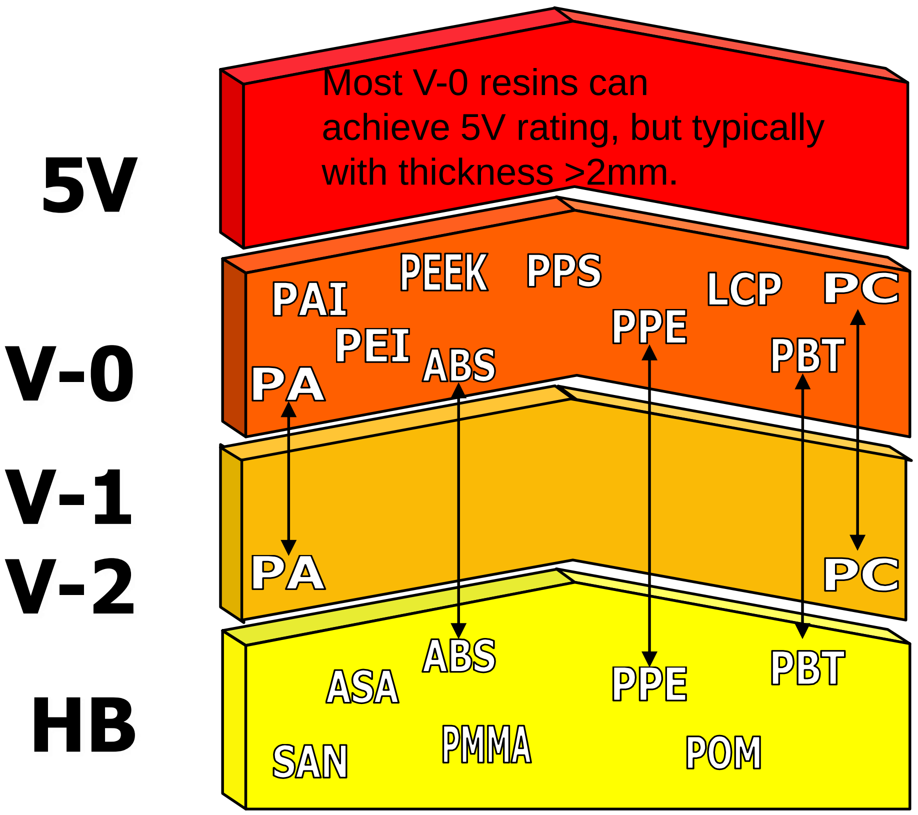
Need to understand risks of using a given material

Flammability of Polymers

- Standard tests developed by UL, CSA, and ISO/IEC
- Additives can improve behavior by
  - Increasing ignition temperature
  - Reducing burn rate
  - Reduce flame spread
  - Reduce smoke emission, toxicity or density
- Self-extinguishing plastics
  - Limiting Oxygen Index (LOI)
    - LOI >21% (greater than standard air) for self-extinguishing (>28% with safety factor)

UL Flame Ratings Explained

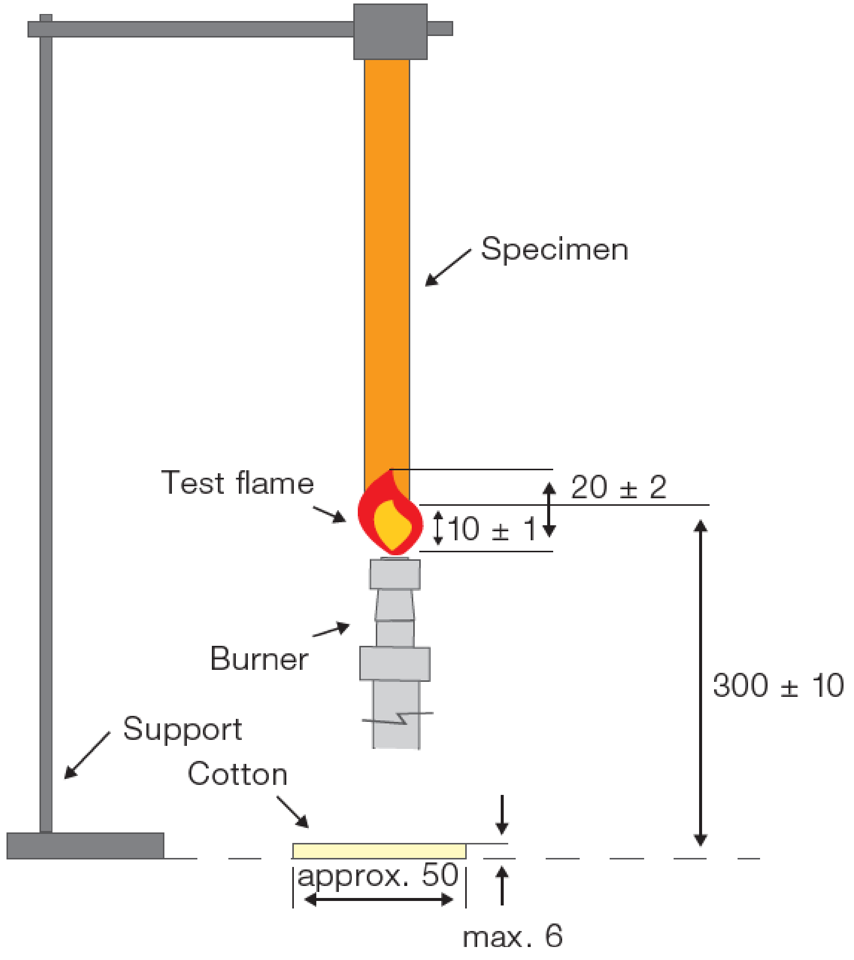
- Flame ratings per UL 94:
  - HB – horizontal burn (lowest rating)
  - V-2 - vertical burn (short time), but flaming drip
  - V-0 – vertical burn (very short time), no flaming drips
  - 5V-A – highest rating – no burn through



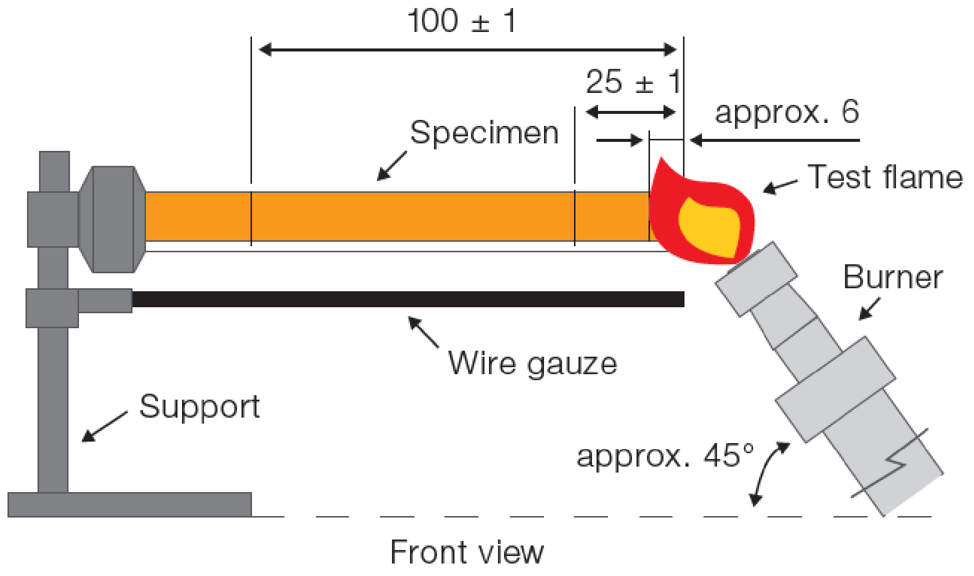
Flame Retardance Testing Set-up

Flame Propagation (UL94)

UL94 V



UL94 HB

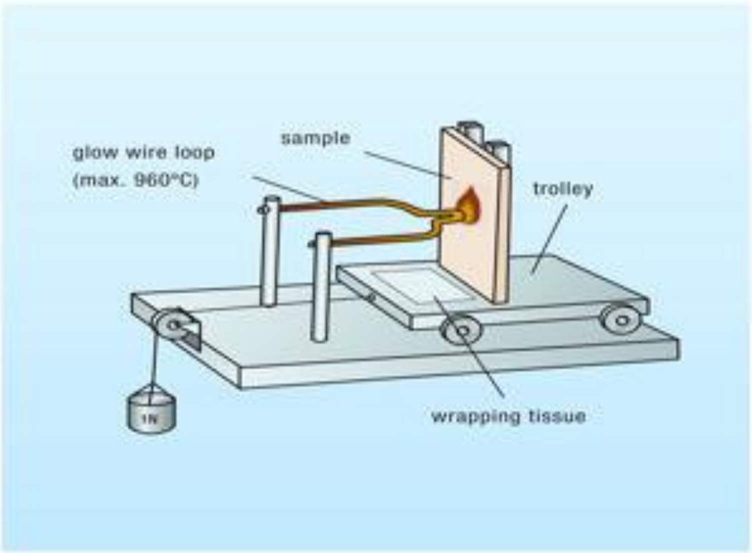


BASF
We create chemistry

Glow Wire Testing (GWIT & GWFI)

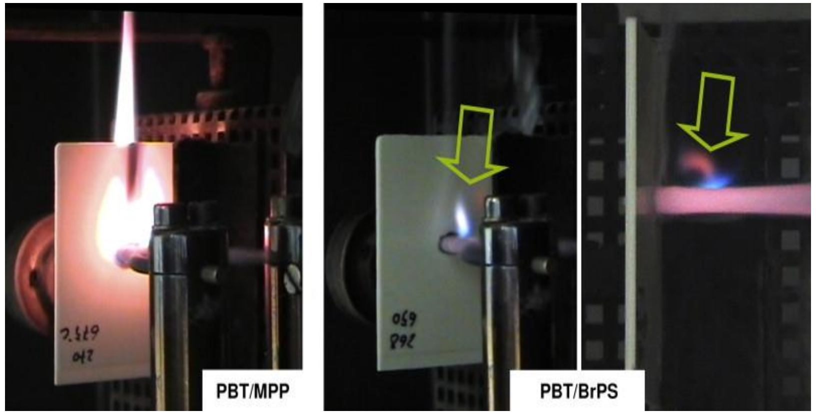
IEC 60335 for appliance and other industry

- Temperature of the wire is clearly controlled and wire is kept in contact with the plaque.
- Strict requirements for electrical components for unattended appliances



Glow Wire Flammability Index (GWFI):
- Afterburning time: < 30 s
- Test duration: 60 s

Glow Wire Ignition Temperature (GWIT):
- Flame: < 5 s



VDE Approved BASF Grades
(IEC 60335 and 60695)

Petra ® 130 FR	PET
Ultramid® A3U40G5, A3K R01, C3U, B3U50G6	PA
Ultradur® B 4441 G5, B4520	PBT

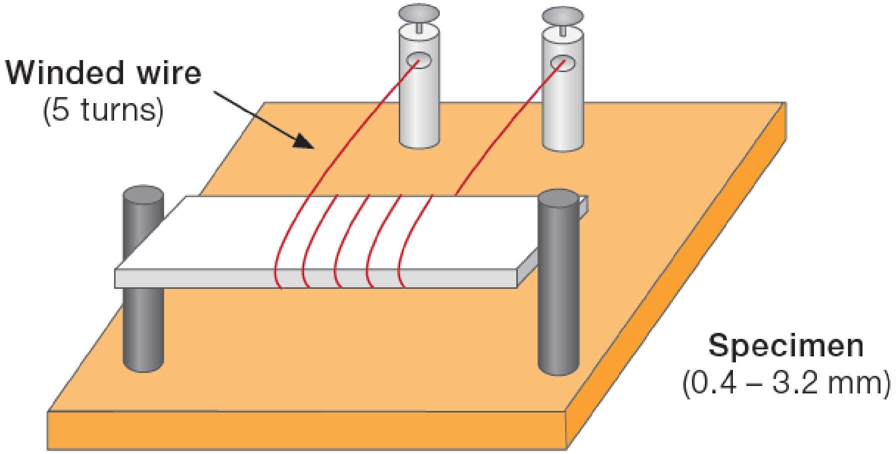
Hot Wire Ignition (HWI)

Ignition time (IT)/s	PLC Class
120 ≤ IT	0
60 ≤ IT < 120	1
30 ≤ IT < 60	2
15 ≤ IT < 30	3
7 ≤ IT < 15	4
0 ≤ IT < 7	5

- Resistance wire is wrapped around plastic and energized electrically for a specified time. Longer time is a better rating – value of 0 is highest offered by UL (120 seconds or longer).

Weakness in testing:

- No control of temperature of the wire – replaced by glow wire in many cases.



Hot Wire Ignition Test (HWI)

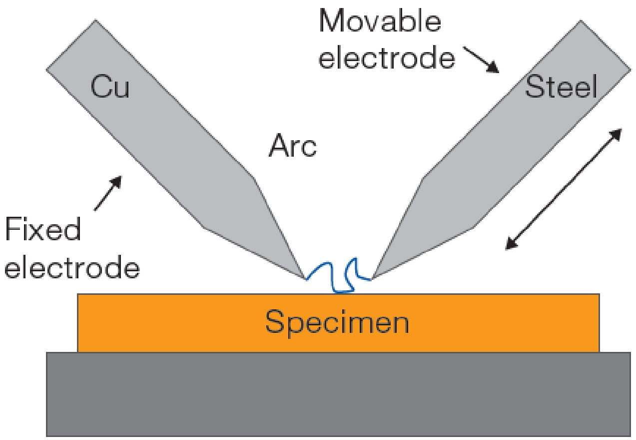
Exposure Time before ignition from electrified wire

High Performing BASF Grades
(values PLC 0)

Petra ® 130 FR	PET
Ultramid® A3U42G6	PA
Ultradur® B 4406 G3	PBT

High Current Arc Ignition (HAI)

- Defined as the number of arc rupture exposures necessary to ignite the material
- Again 0 is best rating offered by UL and corresponds to 120 arcs without burning



U = 250 V AC
I = max. 32.5 A
n = 40 arcs/min

Source: Underwriters Laboratories Inc.®

Number of arcs (NA)	PLC Class
120 ≤ NA	0
60 ≤ NA < 120	1
30 ≤ NA < 60	2
15 ≤ NA < 30	3
0 ≤ NA < 15	4

High Current Arc Ignition (HAI)

Number of arcs withstood before ignition

High Performing BASF Grades

(values PLC 0)

Ultradur® B4450 G5	PBT
Ultramid® 66 H2 G/25-V0 KB1	PA
Ultramid® T KR 4340G6	PPA

BASF We create chemistry

Part Design "Space"
UL 746 C: Choosing Material for Live Electrical Compliance

UL 94 V-0

HAI \ HWI	PLC 0	PLC 1	PLC 2	PLC 3	PLC 4	PLC 5
PLC 0	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Unacceptable
PLC 1	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Unacceptable
PLC 2	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Unacceptable
PLC 3	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Unacceptable
PLC 4	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable

UL 94 V-2

HAI \ HWI	PLC 0	PLC 1	PLC 2	PLC 3	PLC 4	PLC 5
PLC 0	Acceptable	Acceptable	Acceptable	Unacceptable	Unacceptable	Unacceptable
PLC 1	Acceptable	Acceptable	Acceptable	Unacceptable	Unacceptable	Unacceptable
PLC 2	Acceptable	Acceptable	Acceptable	Unacceptable	Unacceptable	Unacceptable
PLC 3	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
PLC 4	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable

UL 94 HB

HAI \ HWI	PLC 0	PLC 1	PLC 2	PLC 3	PLC 4	PLC 5
PLC 0	Acceptable	Acceptable	Acceptable	Unacceptable	Unacceptable	Unacceptable
PLC 1	Acceptable	Acceptable	Acceptable	Unacceptable	Unacceptable	Unacceptable
PLC 2	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
PLC 3	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
PLC 4	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable

Flame ratings can shrink or enlarge your material options for a given application – i.e. higher flame rating will allow for lower performance against electrical line sources.

PLC: Performance level characteristic
HWI: Hot wire ignition
HAI: High amperage ignition

Acceptable (green)
Unacceptable (red)

Insulation/ Isolation

The ability to shield to protect from electrical shock or interference (crosstalk, short or shunt, etc.)

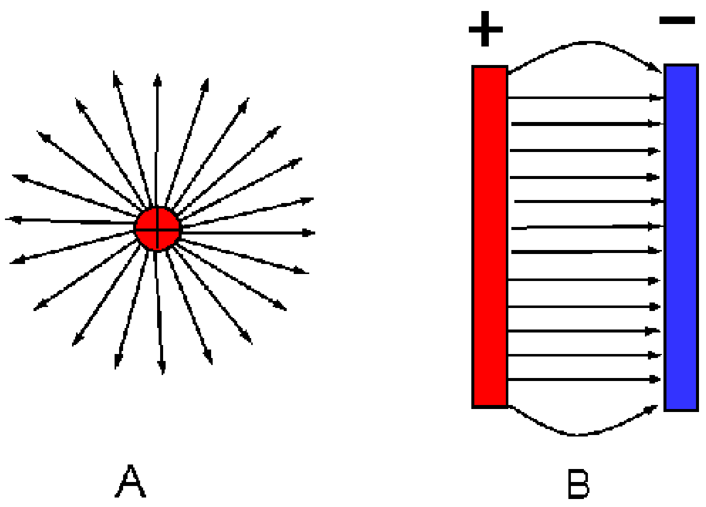
Why It Matters

Circuits need to remain separate and function as designed - safety

Dielectric Strength

- Maximum electric field strength that can be withstood without breakdown or failure of insulating properties

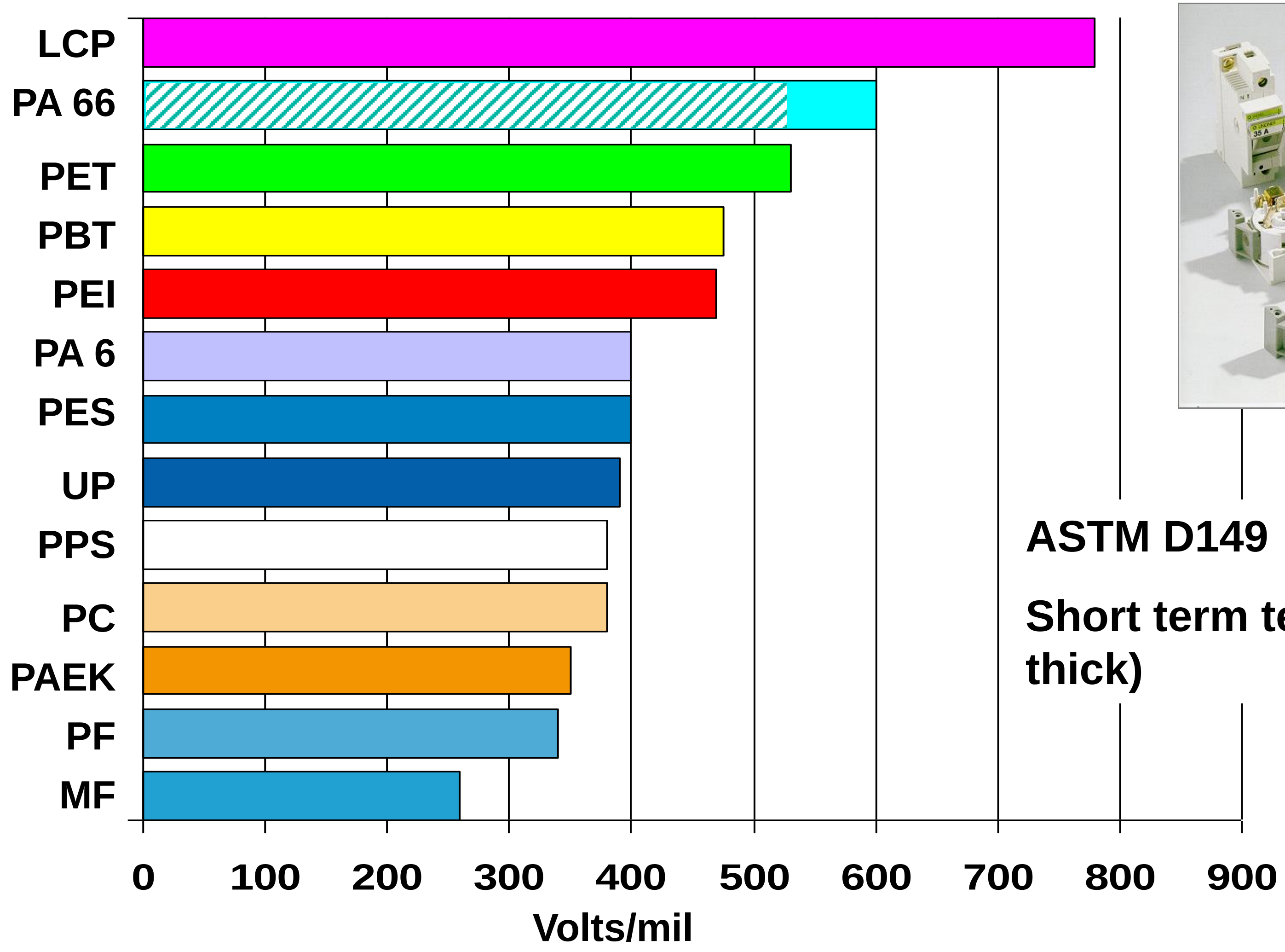
- Laminates (layers of insulation) are generally more effect than a single thicker sheet possibly due to the energy needed to destroy each surface

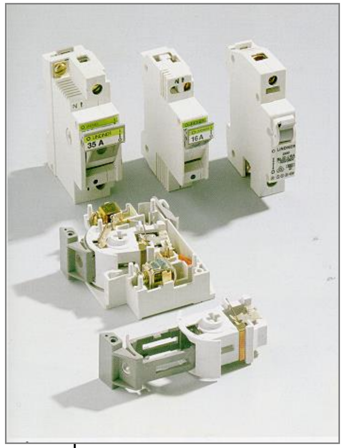


BASF
We create chemistry

Dielectric Strength

Maximum electrical stress/thickness before breakdown





Top BASF Grades

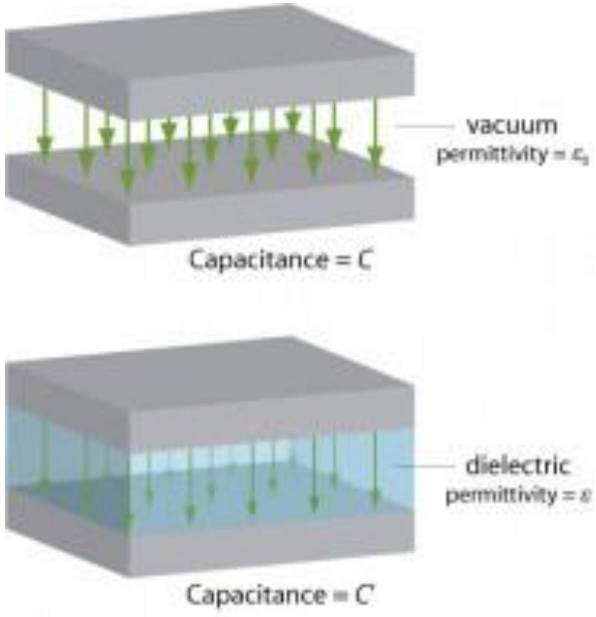
(values above 35kV/mm or 875 V/mil and UL 94 V-0)

Ultradur® B4441 G5	PBT
Ultramid® N3U40G6	PPA
Ultrason® S2010 G2,G4.G6	PSU

Dielectric Constant/ Relative Permittivity

- Shows how effective a material is at allowing a capacitor to store charge. The larger the constant, the more charge can be stored.
    - Can also be negative when trying to dissipate charge (static).
    - Values for many plastics are generally in the 3-4 range.

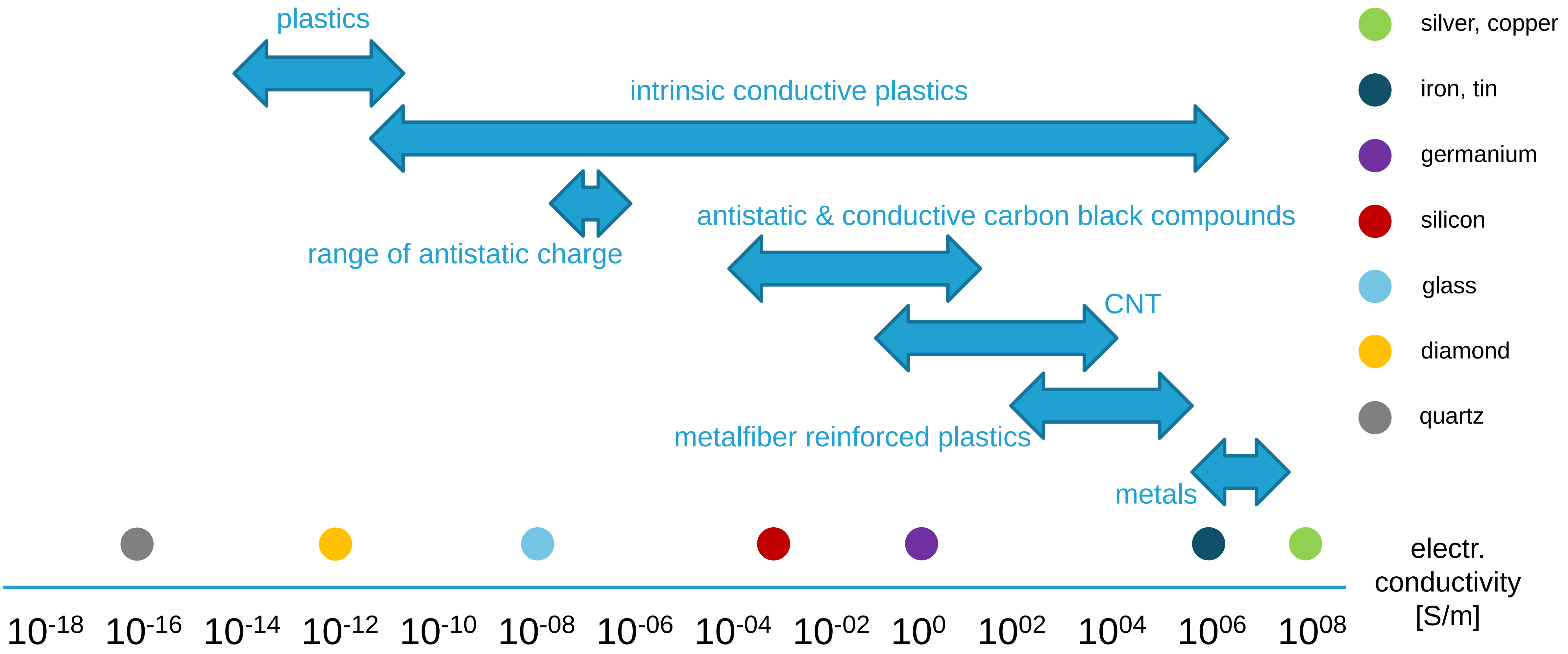
- This is becoming much more important for items such as active safety or signal transmission and reception. Dissipation factor is a related property.



$\kappa = C'/C$ $\kappa = \varepsilon/\varepsilon_0$

Resistivity	Effectiveness of insulation or isolation
Why It Matters	Resistivity changes with temperature and environment

Electrically Conductive Products

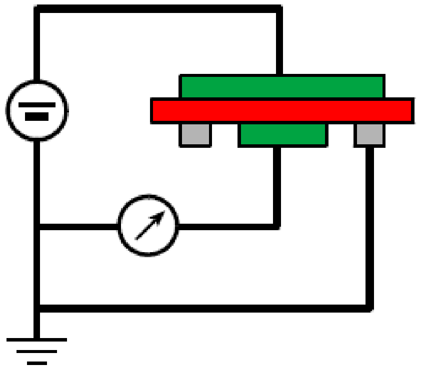


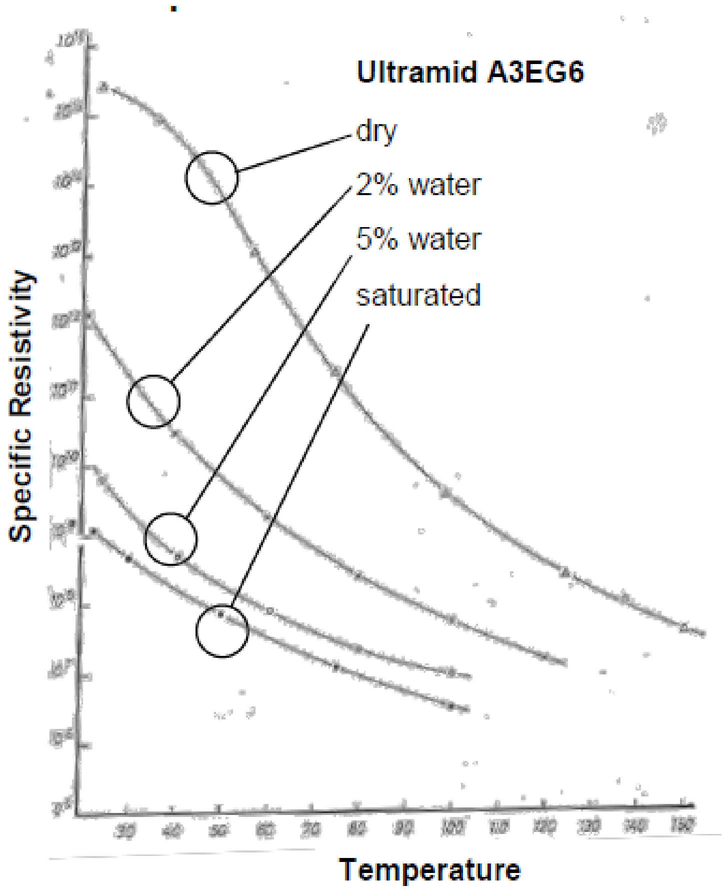
Specific Volume Resistance

- The **specific resistivity** of plastics:
  - Is measured according to IEC 60093
  - Depends on temperature and moisture uptake

Specific Resistivity ρ acc. to IEC 60093

$\rho = (R \cdot A) / d$
R → Resistance measured
A → Area
l → Thickness of sample

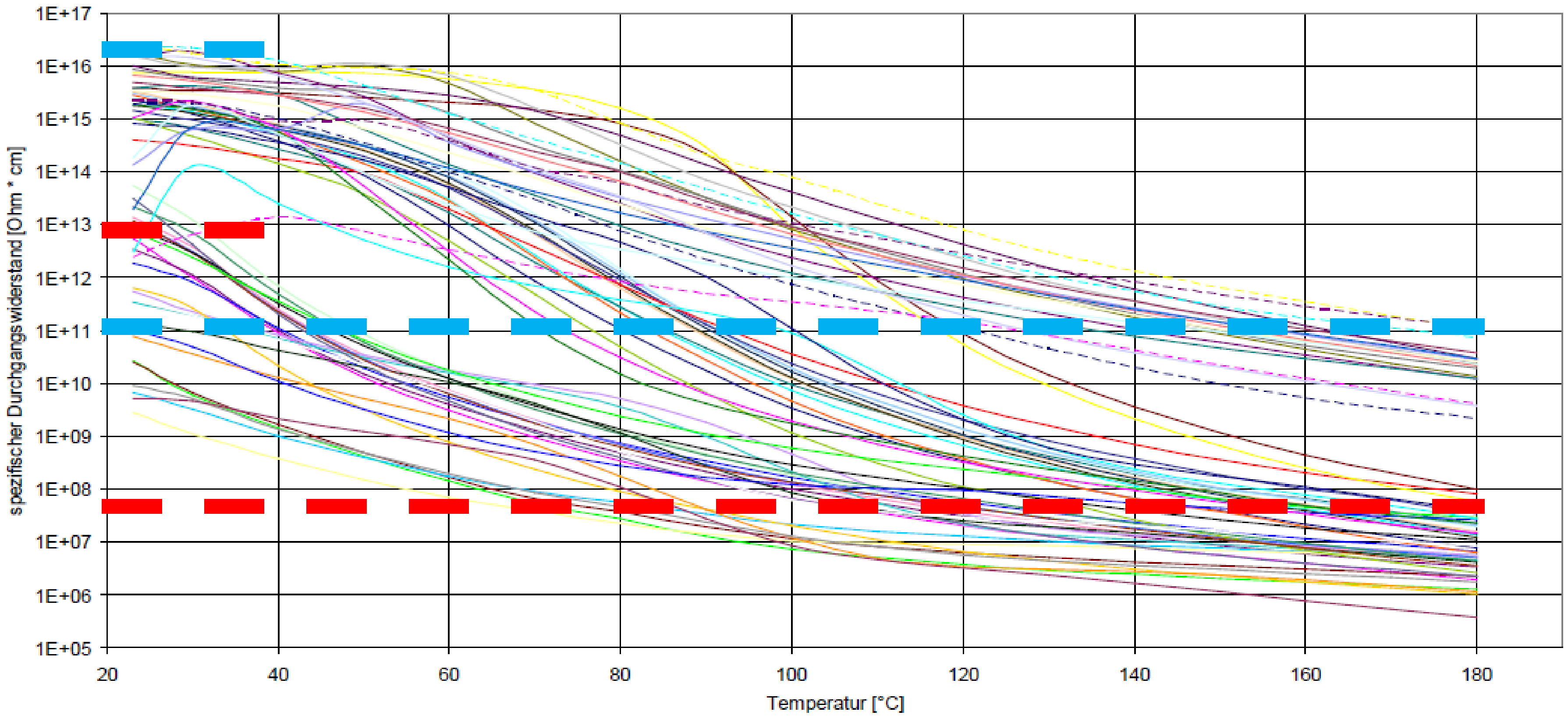




Specific Volume Resistance

Resistance to Ignition | Insulation | Tracking Resistance | Thermal Aging

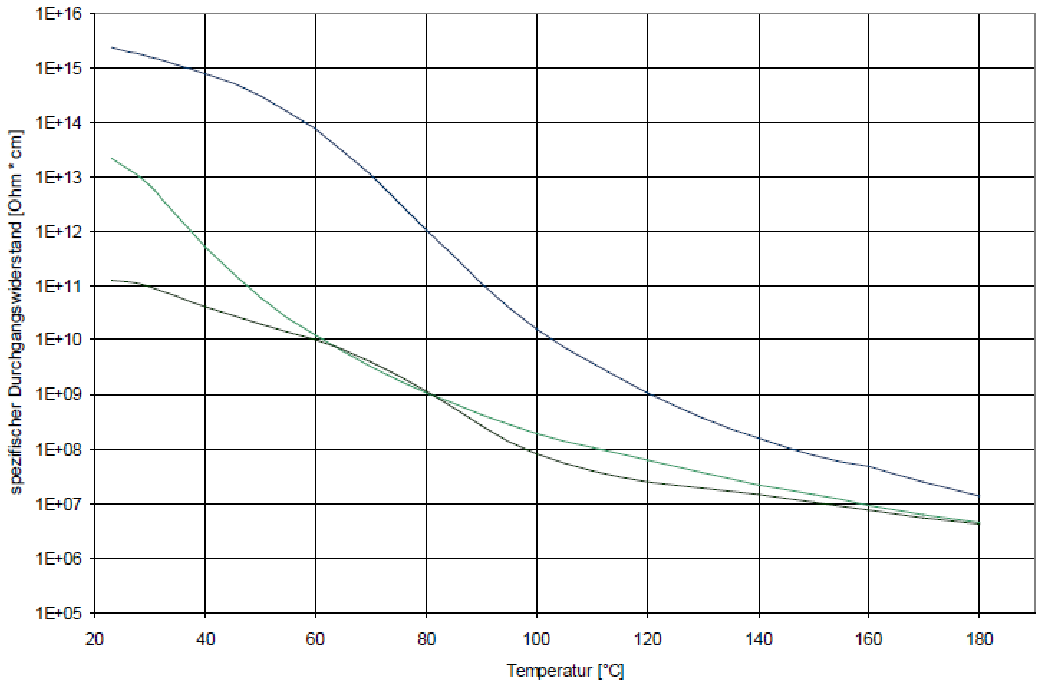
- Most PA and PBT compounds show drop of specific resistance (temp. rises to 180 °C → resistance drops ~10E5, independent of GF/FR) while PBT starts at an elevated value



BASF
We create chemistry

Specific Volume Resistance of BASF FR Materials

Ultramid A3UG5 PA66

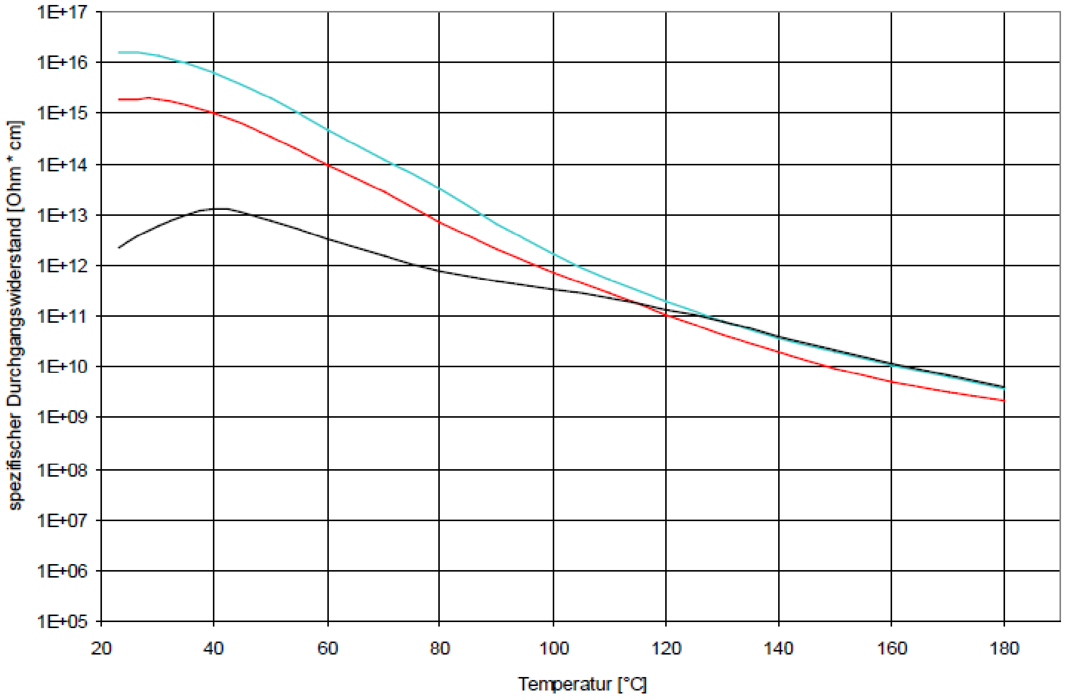


Dry

Moisturized, 14 days at 23C, 50%RH

3 days immersed in water

Ultradur B4450 G5 PBT



Dry

Moisturized, 14 days at 23C, 50%RH

3 days immersed in water

Comparative Tracking Indices

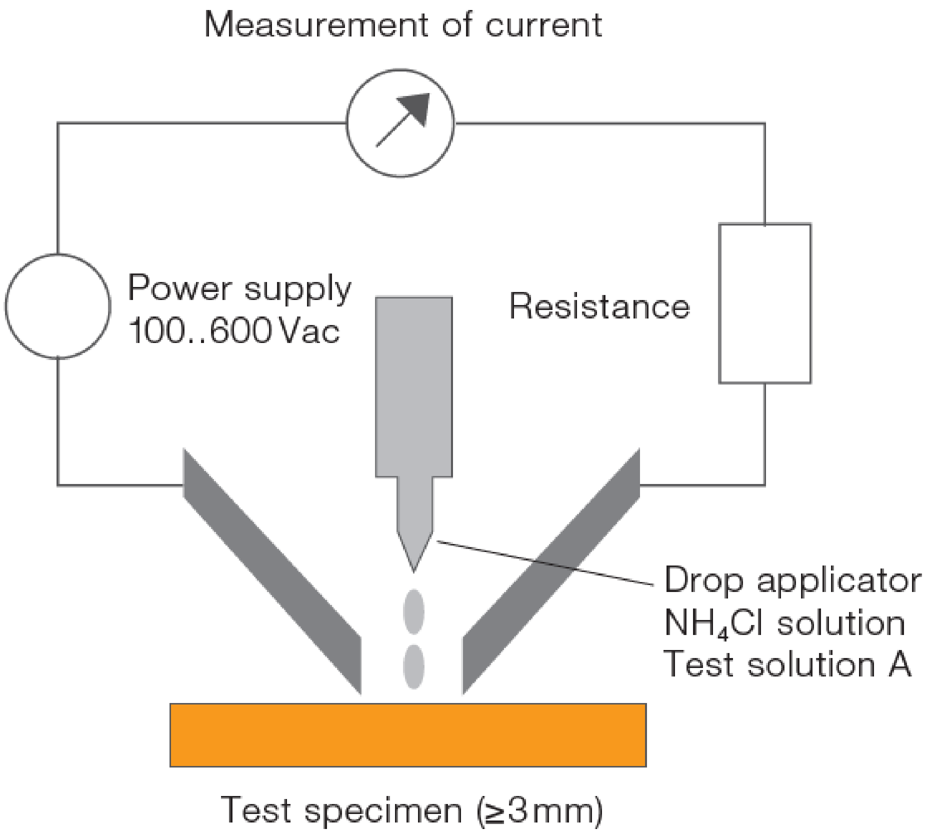
Creating a conductive pathway from charring the surface after arcing

Why It Matters

If a component is likely to experience arcs, it is important to understand the required potential energy required to deposit char on the surface and choose the material with a safety factor.

Comparative Tracking Index

IEC 60112

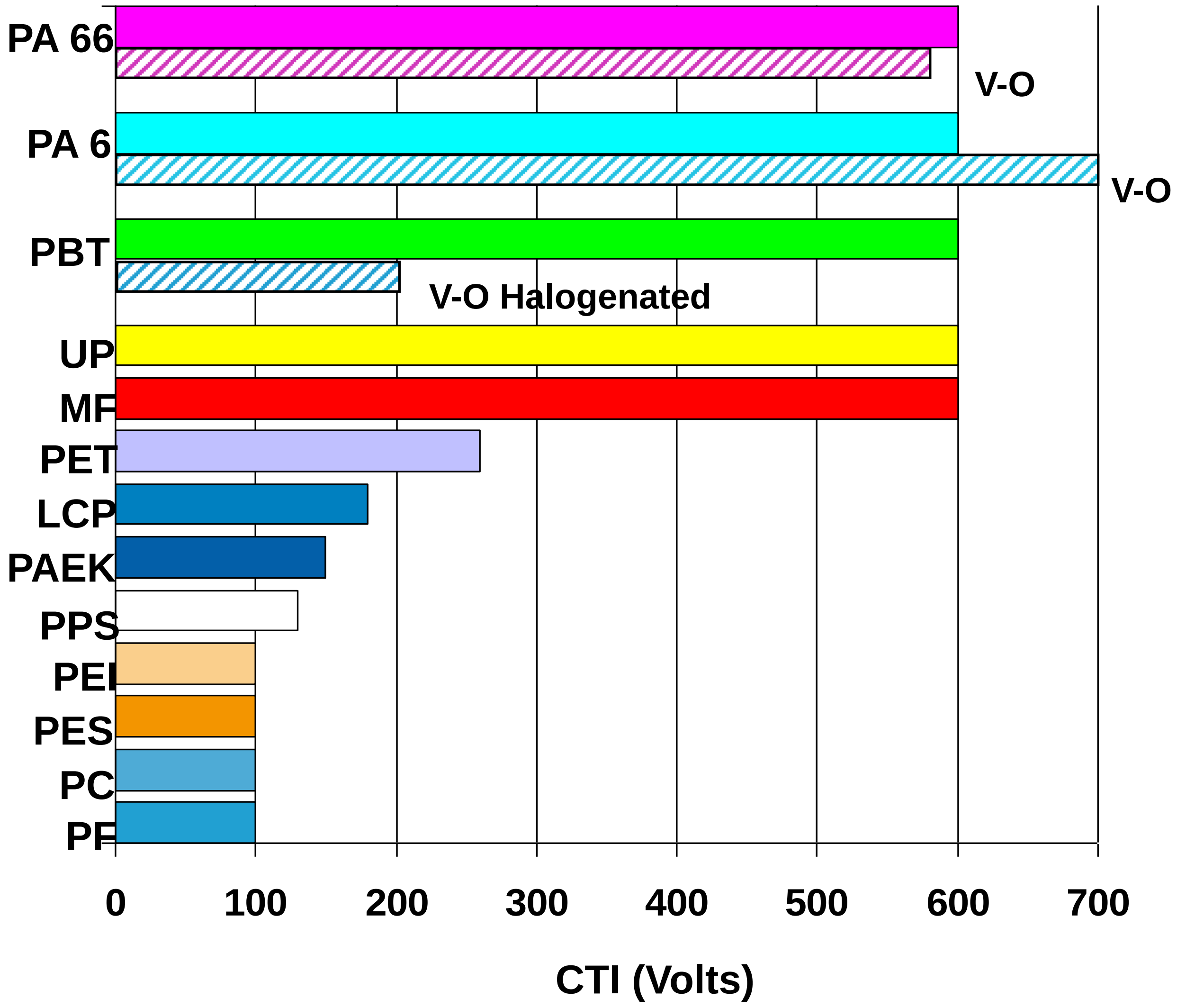


- This test evaluates the materials resistance to create a carbon pathway (short path) in the presence of alternating current (probes) and a conductive solution is added to the surface.

- The voltage is increased until the arc forms the conductive damage or "track" on the surface. The CTI value is the effective voltage limit of the material in use.

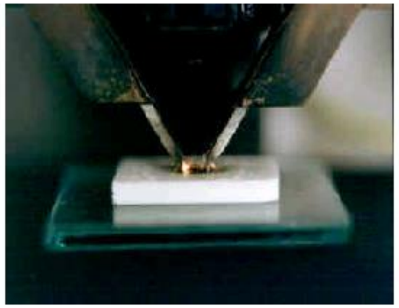
Comparative Tracking Indices

ASTM 3638 (similar to IEC 60112)

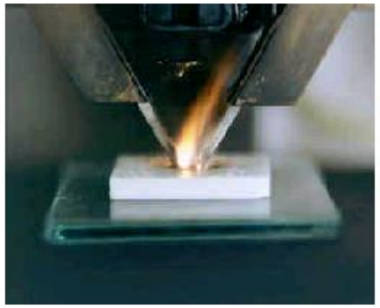


- Just how good is that insulator when exposed to arcing and high voltage in the presence of a conductive solution (i.e. rain, etc.)?
- **Additives Matter:**
  non-Halogenated vs Halogenated FR

Ultradur® B4400



Halogen-containing FR-PBT



BASF We create chemistry

Terminal Spacing

Electrical Creepage

Insulation expectation for equipment for low-voltage systems - **IEC 60664-1**

Contamination Class / Degree of Pollution	
1	None / no conductive pollution
2	Only non-conductive pollution, sometimes conductivity due to condensation
3	Conductive pollution or non-conductive pollution transformed due to moisture

Minimum distances to avoid failures because of creeping for pollution degree 3 (according to IEC 60664-1)

Voltage [V]	Insulating Material Class 1 mm	2 mm	3 mm
250	3.2	3.6	4.0
400	5	5.6	6.3
800	10	11	12.6
1,000	12.6	14	18

Insulation Class	
1	600 ≤ CTI
2	400 ≤ CTI < 600
3a	175 ≤ CTI < 400
3b	100 ≤ CTI < 175

A high CTI-Value allows smaller distances
→ Miniaturization

Thermal Aging

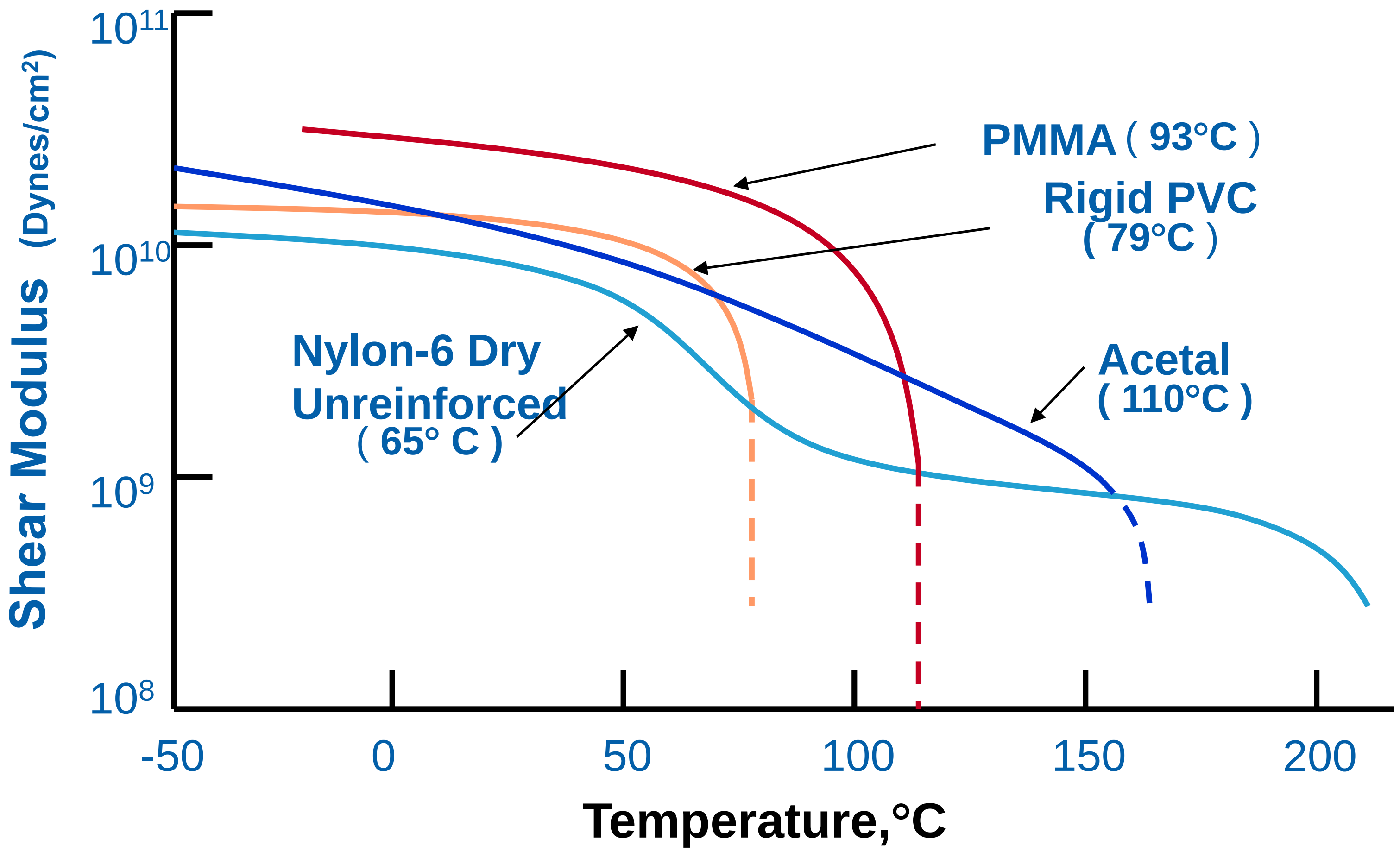
Extended exposure to elevated temperature – effects on mechanical and electrical properties

Why It Matters

Understanding if material is stable in the actual environment or if it will be compromised from heat

Short-term Thermal Properties

Structural Integrity/Stiffness as Function of Temperature (Glass Transition Temperature)



This often confuses people – heat aging versus response to heat

BASF We create chemistry

Relative Thermal Indices (RTI)

Long-term Thermal Aging

- Heat aging is an expectation of electrical products
- Insulation performance and strength retention are critical in long-term use
- Generic values are listed unless a program is done (~65C upper limit)

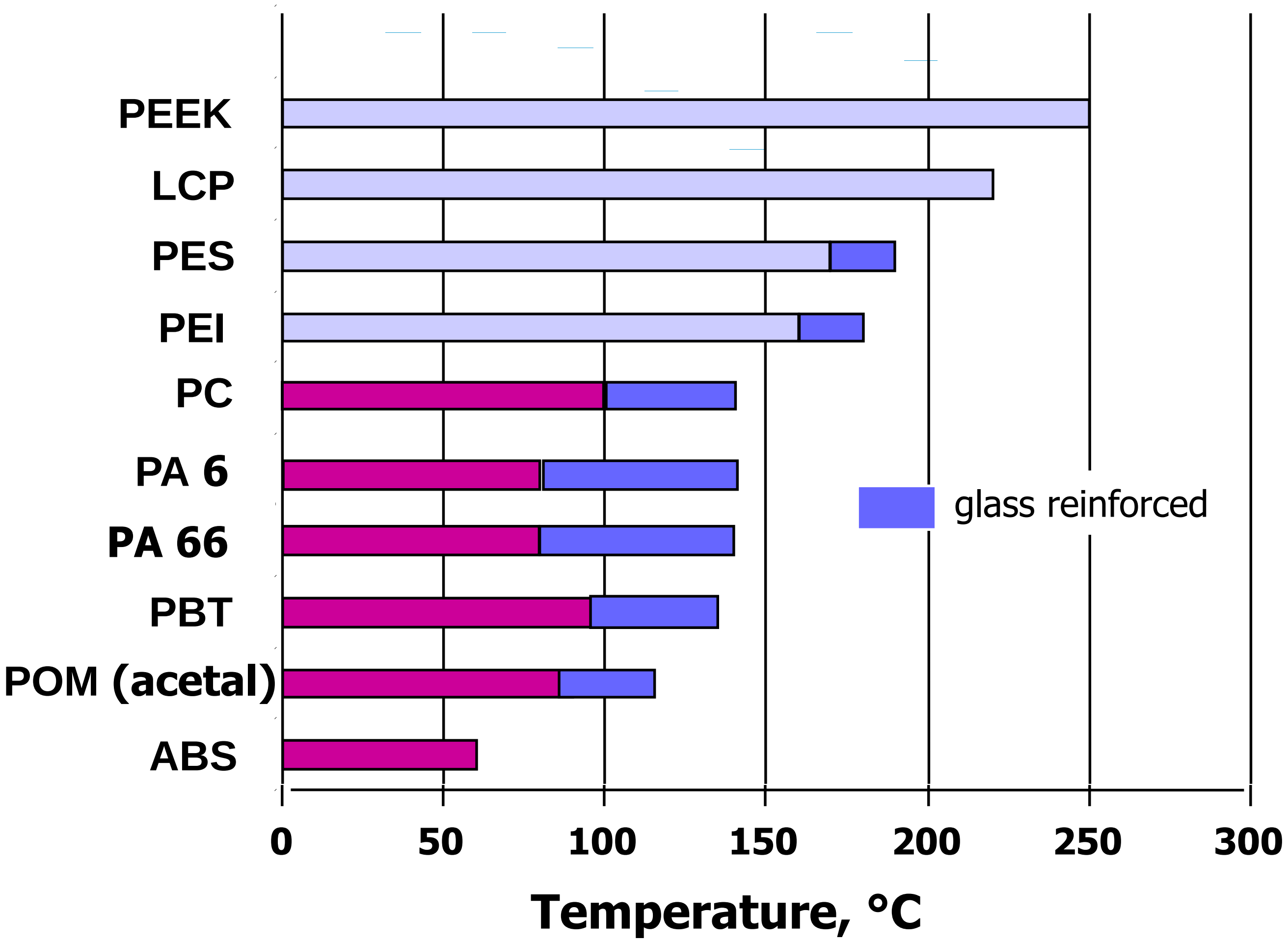
- A new RTI program will take 18-24 months to complete
- UL requires testing to find the upper temperature limit for use of the product (greater than 10,000 hour exposure) – thickness dependent

  - Electrical (insulation performance)
  - Mechanical (strength retention)
  - Mechanical with impact (impact resistance retention)

Relative Continuous Use Temperatures

Resistance to Ignition | Insulation | Tracking Resistance | **Thermal Aging**

50% retention of tensile strength / 20,000 hrs



Test according to UL 746C for long term exposure to heat

RTI (Relative Thermal Indices) for tensile, electrical and impact properties (shown as temperature on UL card)

EMI Shielding

Material's ability to block electromagnetic waves or interference – capability to protect from external "noise" or signals

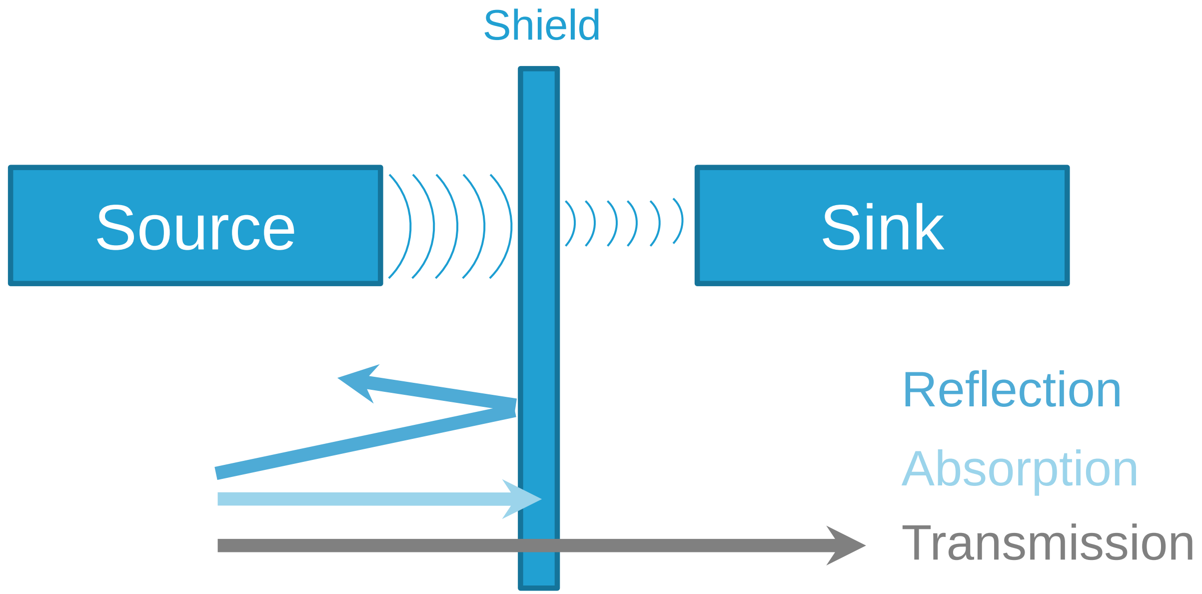
Why It Matters

Needed when multiple modules which create a EM field are located close to each other to ensure they work as designed (eliminate interference)

Generally "normal" polymers are not good EMI shield materials

EMI Shielding

- Electric vehichles with power of 100 kW in narrow spaces
- Voltage between 400 and 800 V
- Power electronics are sources of interference by producing electro-magnetic radiation
- Every other electronic component is a susceptible device → **e**lectro-**m**agentic **i**nterference (EMI) can occur
- EMI shielding protects environment and application against electromagnetic interference
- Electric conductive housings with low resistance required
  - Conductive matrix material
  - Conductive surface



Required range of shielding efficiency

E_0: Field strength ***without*** shield
E_1: Field strength ***with*** shield
SE: **s**hielding **e**fficiency

SE [dB] = 20 ˣ log(E_0/E_1)

SE [dB]	E_0/E_1	Transmitted power
20	10:1	10 %
40	100:1	1 %
60	1,000:1	0.1 %
80	10,000:1	0.01 %

SE = 60 dB → Shield reflects and/or absorbs 99,9 % of electromagnetic energy

Shielding Efficiency of Materials

Injection molded plate with 3 mm wall thickness

Material	Shielding efficiency (at 1 GHz)	Specific electric conductivity
Ultraform® N2320 C (POM-CNT)	15 dB	0.018 S/cm
Ultramid® A3WCG24 (PA66-CF10-GF20)	20 dB	0.039 S/cm
Ultrason® E 2010 C6 (PESU-CF30)	25 dB	0.089 S/cm
Ultramid® B3WC3 (PA6-CF15)	30 dB	0.548 S/cm
Ultramid® A3WC4 & 8 (PA66-CF20 & -CF40)	30 – 35 dB (saturation)	0.618 – 1.44 S/cm
Ultradur® B 4300 C3 (PBT-CF15)	40 dB	2.02 S/cm
PA66 with 30 wt. % steelfibers	90 dB	110 S/cm

Required shielding efficiency:
60 – 80 dB

BASF
We create chemistry

Other Design Considerations

(Properties are not generally on datasheet)

- Fatigue
- Friction and Wear
- Creep (long term loading)
- Environmental effects
  - Chemical resistance
  - Temperature response
  - Effect of heat aging
  - Moisture (certain materials are hygroscopic – absorb water easily)
  - UV light exposure

ABS/ESP steering sensor

Please contact us with any questions you have concerning these topics before designing a part

BASF
We create chemistry

Case Study: Battery Tray and Cover

- ✓ Part dimensions?
  - → Warpage requirements?
- ✓ Structural battery pack?
  - → Strength and stiffness requirements?
  - → Crash requirements?
  - → Must survive a drop test?
  - → Mechanical stress requirements?
- ✓ Flame retardant requirements?
  - → What is the distance from the bus bar?
- ✓ CTI
  - → What is the distance from the bus bar?
- ✓ Orange colorable?

Application	Grade	Polymer Type	Fill	UL	Benefits
Tray	**Ultramid® B3UGM210**	PA6	10%GF 50%MF	V0 @ 1.5 mm	▪ Lower warpage ▪ Improved thermal conductivity ▪ Halogen-free
Cover	**Ultramid® B3U Q717**	PA6	None	V0 @ 1.5 mm	▪ Halogen-free

BASF
We create chemistry

Design Consideration Overview

Electrical does not operate independent of all other properties

Application Processing

- ❑ Preferred processing method?
- ❑ Existing tool or open to new?
- ❑ Matching flowability with another material?
- ❑ Overmolding required?
- ❑ What part of the product is this for?
- ❑ Any processing restrictions?
- ❑ Tool maintenance concerns
- ❑ Fastening method (welding, adhesives, mechanical, etc.?)
- ❑ Laser sensitivity required (other marking)?

Part Geometries

- ❑ Thickness restrictions for design?
- ❑ Size restrictions for design?
- ❑ Volume of designed part?

Mechanical Operations Life

- ❑ Loading expectations
- ❑ Cyclic loading (fatigue)?
- ❑ Creep of long term loading
- ❑ Friction and wear requirements

Temperature Range of Operation

- ❑ Heat aging - retention of properties (time and temp.)
- ❑ Dimensional stability and moisture barrier?
- ❑ Hydrolysis stability needed (high temp. and humidity)?

Flammability

- ❑ Does it need to be flame rated (UL 94)?
- ❑ Any specifics on UL listing or other approval?
- ❑ Glow wire or unattended appliance requirement?

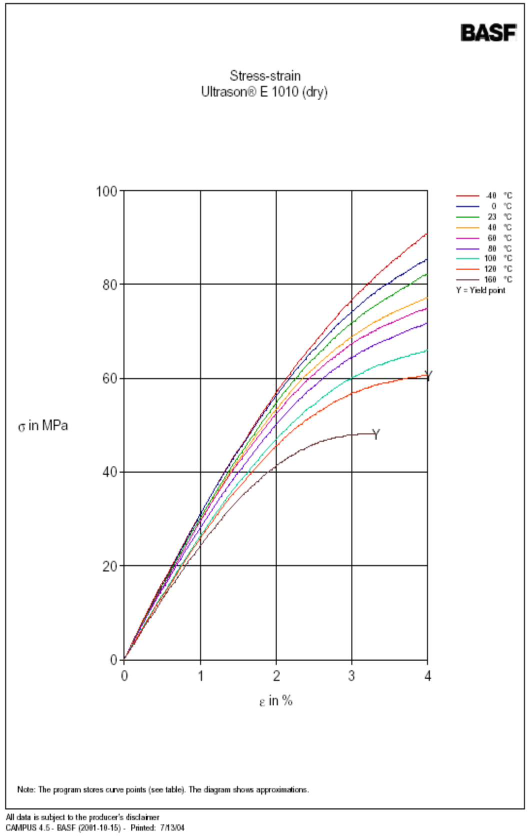
Special Requirements

- ❑ Does the part see UV?
- ❑ Chemical exposure needs
- ❑ Need RoHS or other approvals
- ❑ Any restricted materials (halogen, copper, etc.)?
- ❑ Any special environments (nuclear for example)?
- ❑ Warpage concerns (mating to another part)?
- ❑ Colorability?

Thank You

Additional Resources

https://materials.ulprospector.com/en



[CAMPUS](http://www.campusplastics.com)

[*www.campusplastics.com*](http://www.campusplastics.com)

Computer Aided Material Pre-Selection

This program has much more information including stress-strain curves and creep, rheology, and shear modulus data

BASF
We create chemistry

We create chemistry