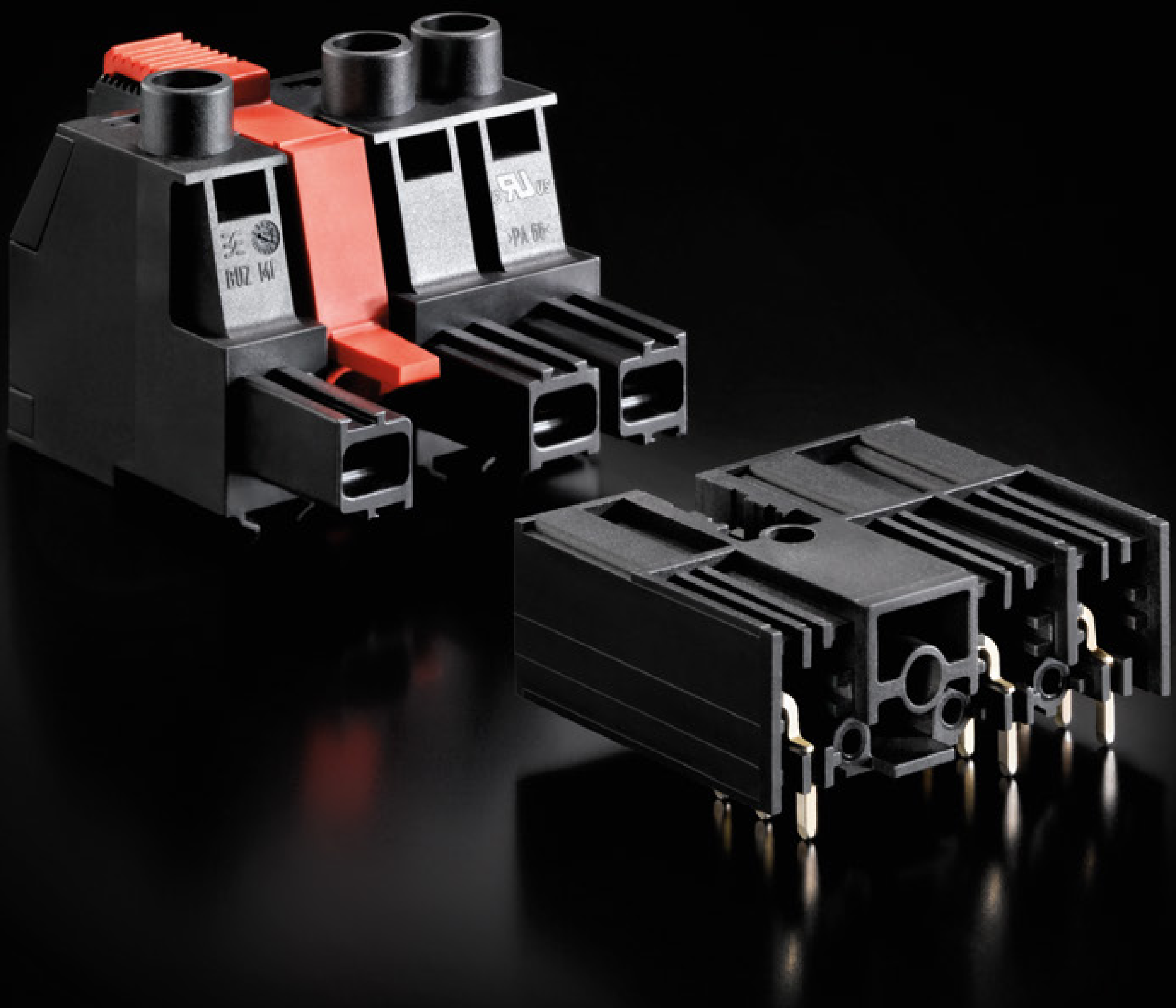
# QUALITY CONNECTS.

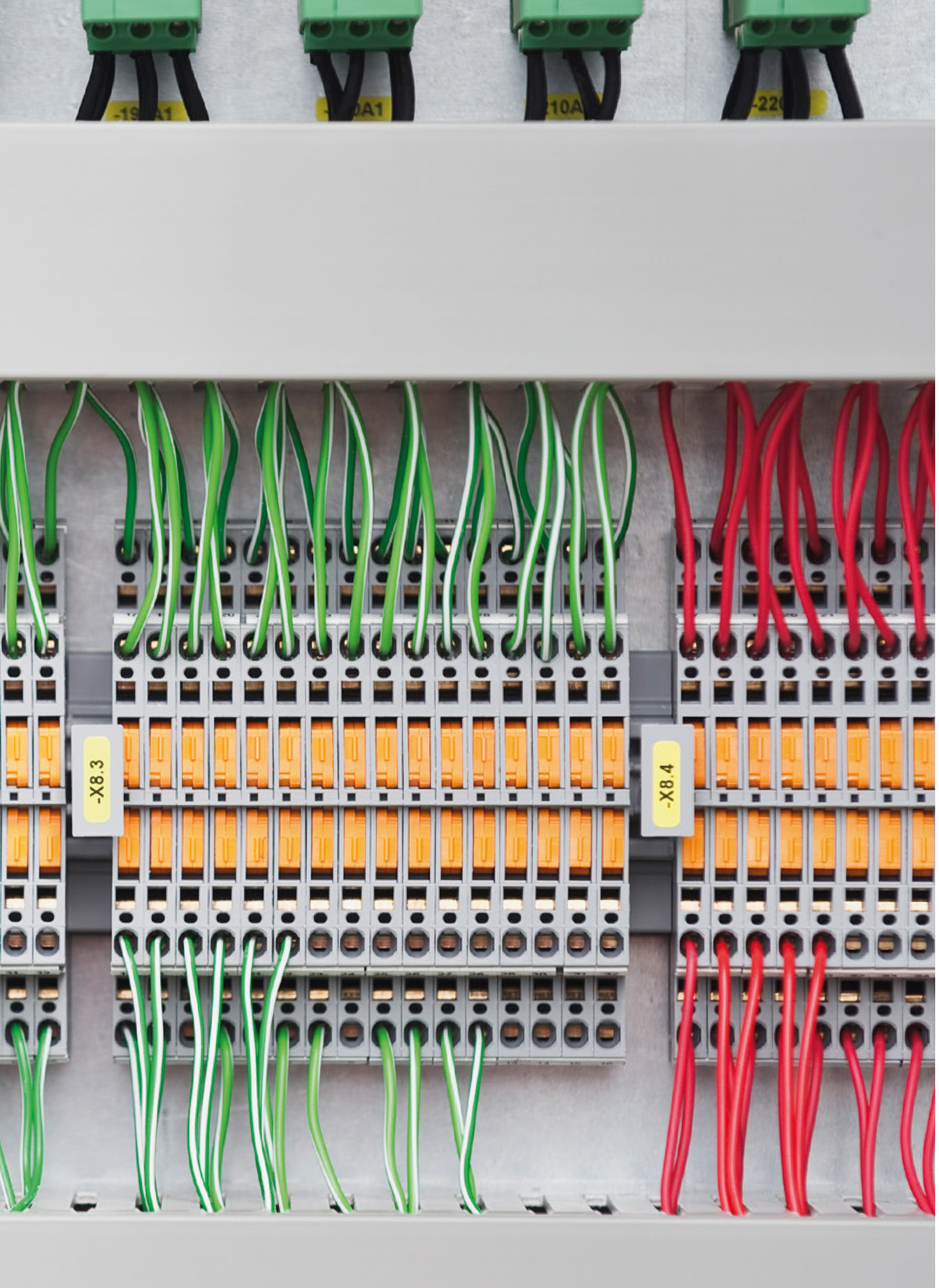


High-Tech Thermoplastics for the **E&E Industry**
Standards, Testing, Materials, Applications

Durethan® Pocan® HiAnt®

QUALITY WORKS.

LANXESS
Energizing Chemistry

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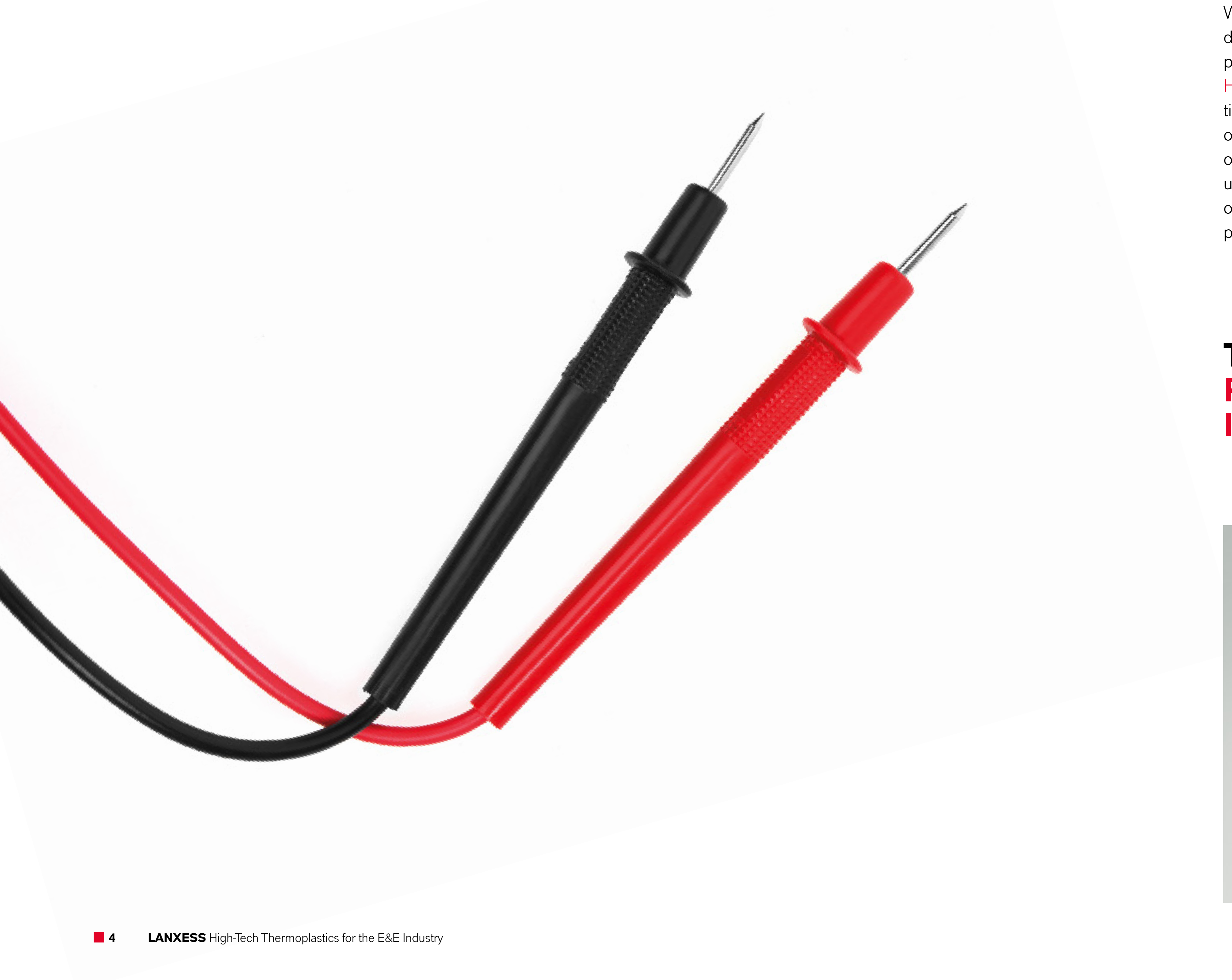
# THE INTERNATIONAL E&E SEGMENT – OUR PARTNER INDUSTRY

Whether it's Industry 4.0, digital networking of smart home technology, domestic appliances and entertainment electronics, or intelligent power grids for the energy revolution, IT security or electric mobility – practically all key issues of the future and megatrends worldwide depend on innovations in the area of electrical and electronics (E&E). And plastics have a vital role to play in these developments. They are among the most important design materials for E&E components. That's why LANXESS offers the growth industry E&E a range of innovative Durethan® and Pocan® brand thermoplastic materials that meet the latest requirements.

The specialty chemicals company makes it a top priority to ensure its materials fulfill the E&E industry's international standards – whether used in components for industrial applications, household appliances, LED lighting technology, consumer and home electronics, or power tools. And LANXESS also collaborates closely with partners from the E&E industry, providing new materials and technologies to help realize development trend breakthroughs.





# OUR AREAS OF EXPERTISE – A BROAD SPECTRUM

With production plants in all important trade regions, LANXESS is a leading supplier of products including compounds based on polyamide 6 and polyamide 66, as well as polyesters like polybutylene terephthalate (PBT). It is exactly these plastics that are very widely used in the production of E&E components. So LANXESS clearly has decades of experience with the E&E industry. Furthermore, our experts serve on important committees and in organizations for standards and testing – for example UL and TC 89 – and thus have extensive knowledge of the industry's needs, particularly when it comes to electrical and fire safety.

We stand out from most of our competitors thanks to our in-depth know-how in development of materials, applications, processes and technology. We have combined all that in the HiAnt® brand, thus helping customers at all levels of application development – from the concept phase and materials optimization to the start of series production. Unlike most of our competitors, we are highly backward-integrated in the value chain of our high-tech plastics. For example, we produce our own glass fibers for our compounds and raw materials for polyamide 6, at world-scale facilities.

Overall, our customers in the E&E sector benefit from:
- optimal reliability of supply and delivery
- controlled production costs for our plastics
- the certified high quality of our products, uniform worldwide
- development know-how focused on the E&E industry
- a network of regional and local centers for development of products and applications, spanning the globe and close to our customers
- HiAnt® custom services for customer needs in all stages of component development

# THERMOPLASTICS – PROVEN PERFORMERS IN E&E APPLICATIONS

The electrical insulation properties of our thermoplastics offer a major advantage in E&E applications. Also highly valued by customers are not only the great design flexibility they allow in the design of components, but also possibilities for integrating functions by means of injection molding. Direct integration of guides, fastening elements or retainers, for example, simplifies subsequent assembly and reduces logistics costs, which also means lower production costs. Design freedom, integration of functions and light weight are the reasons that thermoplastics have become established as the E&E industry's material of choice in many E&E applications. This is also due to freedom of design in terms of color and surface structure, and the excellent surface quality and coatability of the plastic components. Fiber-reinforced thermoplastics enable production of structural components that are lighter but still also display excellent mechanical strength.

# OUR EXPERTISE – SAFETY WITH ADDED VALUE

Plastics are generally flammable. So they must offer the highest degree of electrical safety and fire safety. In many E&E applications (but by no means all), this requires use of flame-retardant materials, although specifications for flame retardance can vary greatly depending on the specific application. The requirements are defined in national and international standards, regulations and guidelines, which specify test methods a plastic must be able to stand up to. Whether or not the product will even be considered for certain E&E applications is determined above all by its ability to pass certain tests.

This is why our polyamides and polyesters for safety-relevant E&E applications are developed primarily with these test methods in mind. In doing so, we simultaneously take into account ecological, commercial and market-specific factors. That is in addition to findings and experience we have gained from our participation in standardization bodies, e.g. for fire safety.

We take a very targeted approach to ensuring our materials that contain flame-retardant additives (and those free of them) provide further benefits offering added value to our customers. These include the following examples:

- a wide processing window
- good flowability
- excellent thermal resistance
- excellent thermal conductivity
- excellent light stability and light reflection
- good suitability for welding and laser marking


# SELECTED APPLICATION-RELATED STANDARDS – AN OVERVIEW

In this section we present the most important standards and test methods, because they play a crucial role in the selection of plastics for E&E applications.

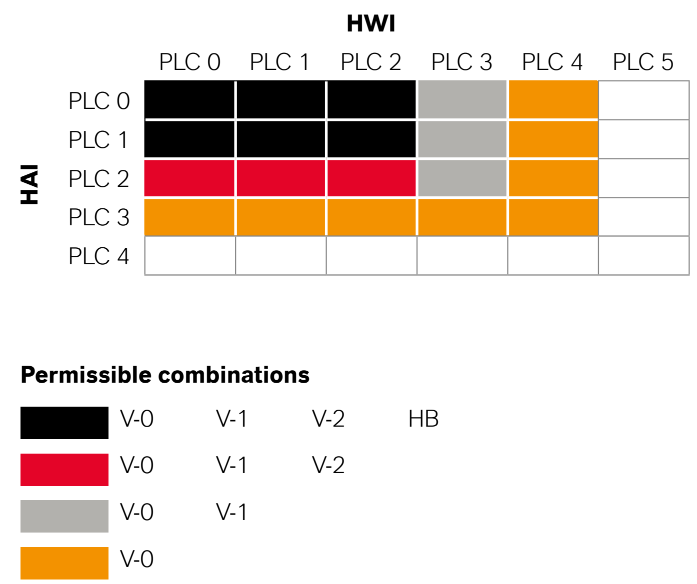
**UL – Yellow Card**

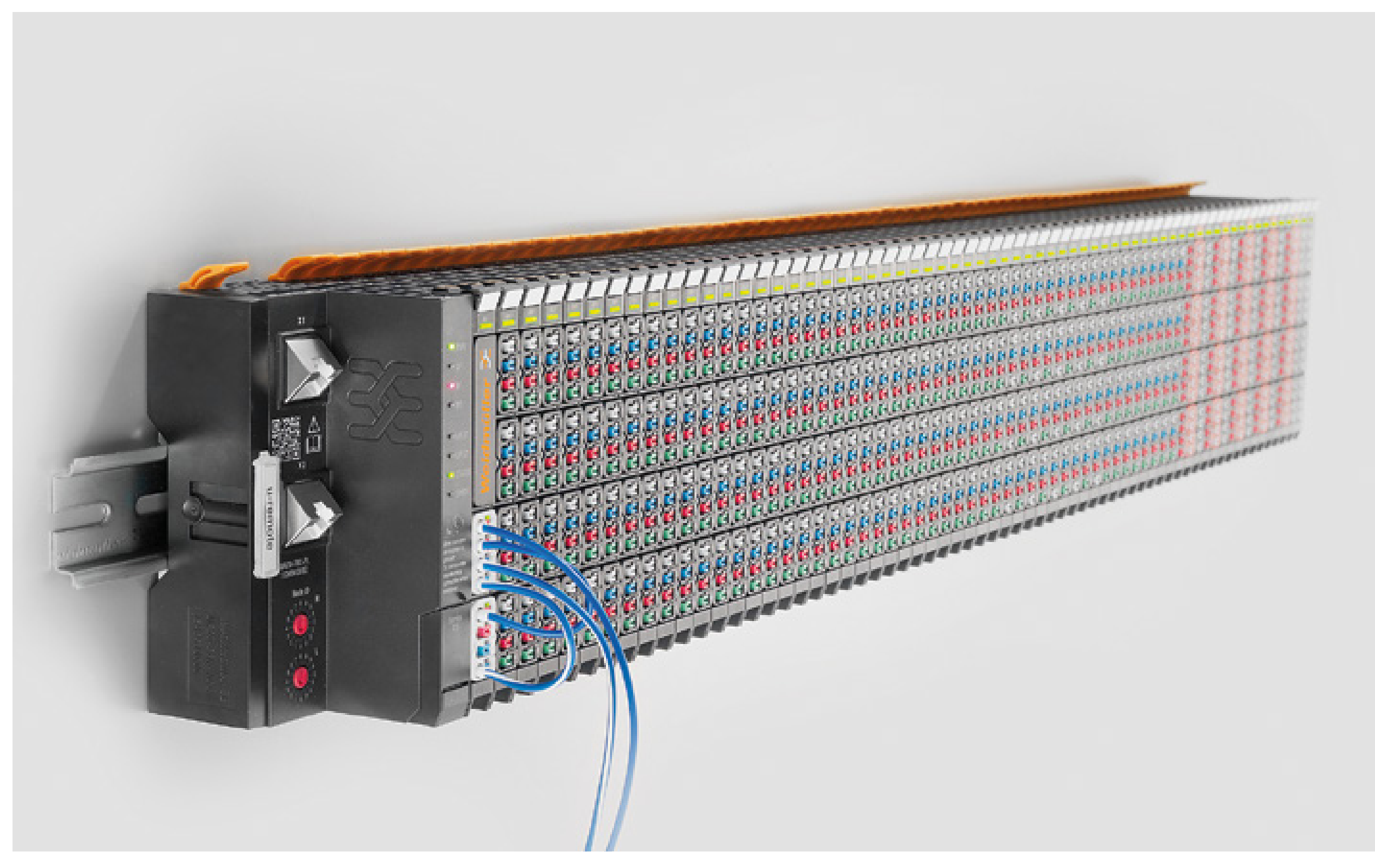
The U.S.-based testing organization Underwriters Laboratories (UL) tests products to certify their safety. Passing the UL tests is mandatory for electrical devices and appliances intended for use in the American market, but it is often required in other countries as well. Plastics manufacturers commission UL to systematically evaluate their products intended for use in electrical components and finished parts. This involves optional testing particularly of their flame retardance, electrical behavior and continuous use temperatures. The test results are documented on what is known as the "Yellow Card." Manufacturers of electrical components can use the card to find plastics suitable for their needs, while also reducing testing costs for a UL certification. The Yellow Cards for the relevant Durethan® and Pocan® types are listed at UL under the LANXESS file number E245249.


**UL 746C – "Standard for Polymeric Materials – Use in Electrical Equipment Evaluations"**

Within the scope of UL applicability, plastic used as an insulating material in electric components must pass various flammability and ignition tests. These are specified in the UL 746C[1] standard. The specific performance required of the individual plastic is determined also by where the appliance/device will be used. The requirements vary depending on whether the device or appliance is used in indoor spaces or outdoors, and whether or not it is exposed to severe weathering and soiling. Certification in accordance with UL 746C is based on fire classification in accordance with UL 94 (V-0 to HB) and on the results of the Hot Wire Ignition (HWI) test and the High Amp Arc Ignition (HAI) test.

**Flammability and ignition tests for plastics in E/E applications (in accordance with UL 746C)**



# SELECTED APPLICATION-RELATED STANDARDS – AN OVERVIEW

**DIN EN 60664-1 – "Insulation coordination for equipment within low-voltage systems"**
This standard specifies, among other things, the requirements for air clearances, tracking distances and fixed insulation of equipment. A susceptibility to formation of tracking distances depends on the properties of a plastic and is described by means of the Comparative Tracking Index (CTI). In accordance with DIN EN 60664-1[2], plastics are divided into Insulation Material Groups. The CTI is determined in accordance with IEC 60112[15].

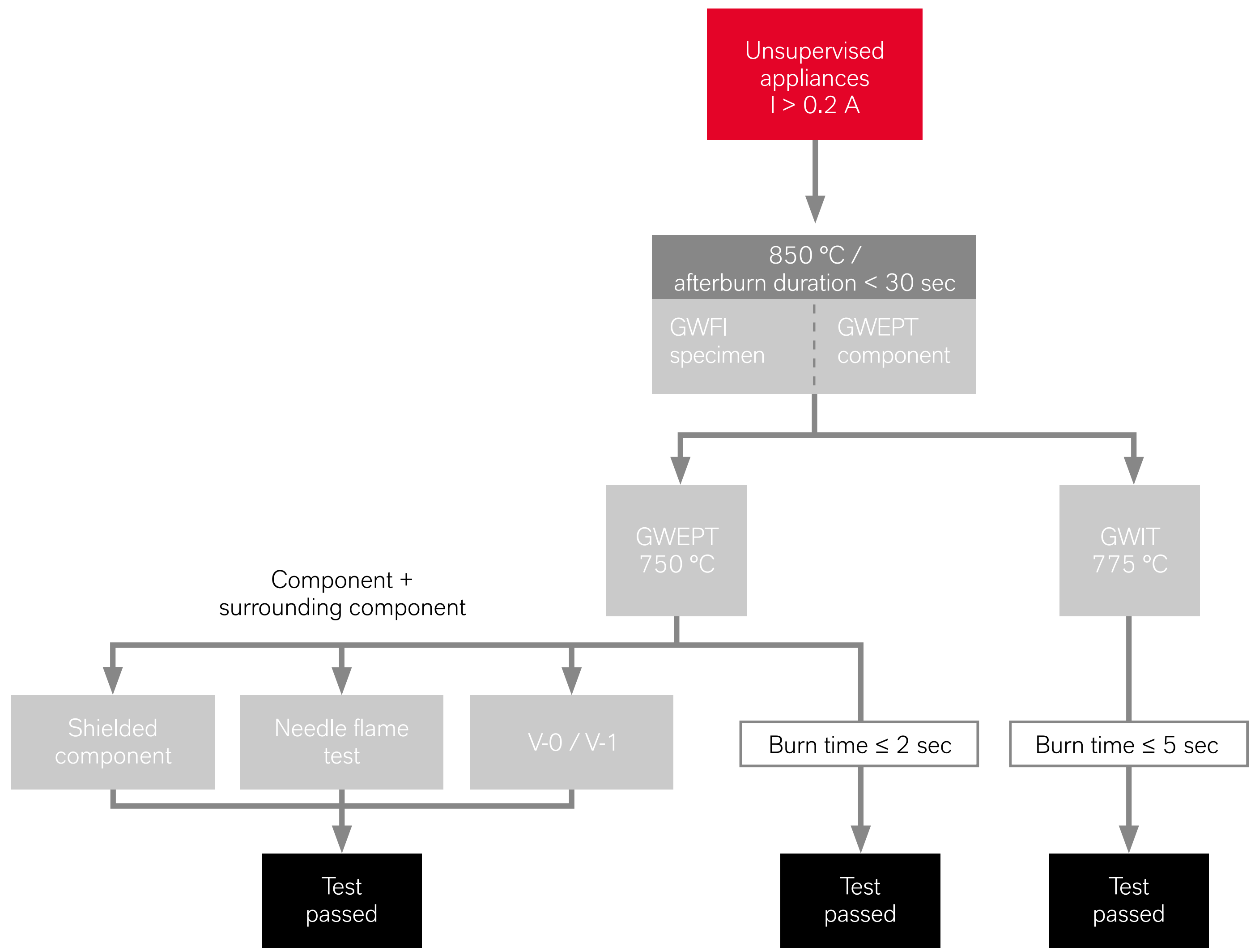
| | |
|---|---|
| **Insulation Material Group I:** | **600 ≤ CTI** |
| **Insulation Material Group II:** | **400 ≤ CTI < 600** |
| **Insulation Material Group IIIa:** | **175 ≤ CTI < 400** |
| **Insulation Material Group IIIb:** | **175 ≤ CTI < 175** |

**DIN EN 60335-1 – "Household and similar electrical appliances – Safety"**
The extended DIN EN 60335-1[3] standard for domestic appliances covers electrical, mechanical and thermal hazards, as well as fire and radiation hazards related to household electrical appliances and similar products. Section 30 of the standard summarizes the requirements for heat resistance and fire resistance. The flame retardance of the insulation material is tested by means of glow-wire tests in accordance with IEC 60695. Which requirements must be fulfilled depends on the current in the appliance and on its mode of operation (supervised or unsupervised).

The most stringent requirements apply to insulation materials in unsupervised appliances with rated currents above 0.2 ampere (see the graphic). Plastics used in such applications must categorically pass a glow-wire ignition temperature test in accordance with IEC 60695-2-12[4b] (GWFI, Glow Wire Flammability Index, afterburn duration max. 30 seconds) at 850 °C. In addition, a glow-wire test on test plates must be fulfilled in accordance with IEC 60695-2-13[4c] (GWIT, Glow Wire Ignition Temperature, max. combustion duration with flame formation five seconds) at 775 °C. If this test is not passed, a test on the finished part in accordance with IEC 60695-2-11[4a] (GWEPT – Glow Wire End Product Test) can be conducted instead. For this method, the temperature must reach 750 °C, however it involves more rigorous conditions (max. afterburn duration of two seconds permitted). Alternatively, certification is possible if the surrounding components meet at least the requirements of Class V-1 in accordance with UL 94[6] or pass the needle flame test in accordance with DIN EN 60695-11-5.




**Excerpt from IEC/DIN EN60335-1, test sequence for unsupervised appliances with rated current greater than 0.2 A**



# SELECTED APPLICATION-RELATED STANDARDS – AN OVERVIEW

**EN 45545-1,-2[7a,b] "Fire protection on railway vehicles"**
This European Standard regulates, among other things, the requirements for fire safety where flammable materials and components are used in railway vehicles. It has been in effect since 2013 and will replace the national standards by not later than 2017. The requirements for E&E components are provided in the table "Requirements for listed components." An "R" requirements set is assigned to the listed components. It includes a number of tests. Which tests must be carried out on the material and which limits must be complied with at which hazard level are listed in the table "Material requirements." The hazard level depends on the rail vehicle design and the type of rail transportation – referred to as the design and operation categories. This differentiation reflects the length of time the passengers spend in the rail vehicle during a fire and how much they are endangered as a result. A hazard level that classifies the potential risk is defined for each design category, based on the operation category. A total of three hazard levels (HL 1 – 3) are defined, with HL 3 being the highest. The main tests for E&E components made of plastic serve to determine the maximum visible smoke production in accordance with EN ISO 5659-2[8] and analyze gases in accordance with NF X70-100-1/-2[9].

### Requirements for listed components

| Component No. | Name | Description | Requirement |
|---|---|---|---|
| **E** | **Electronic equipment** | | |
| EL5 | Components of the supply system – exterior | Surge arresters, insulators, switches, main switches | R23 |
| EL6A | Supply line system components and high-voltage components – interior | Insulators, current and voltage transformers, main switches, contactors | R22 |
| EL6B | Supply line system components and high-voltage components – exterior | Insulators, current and voltage transformers, main switches, contactors | R23 |
| EL7A | Throttles and coils – interior | Throttle coils for filtering the supply line, windings for air-cooled transformers, including spacers and air deflectors | R22 |
| EL7B | Throttles and coils – exterior | Throttle coils for filtering the supply line, windings for air-cooled transformers, including spacers and air deflectors and insulation of the traction motor winding | R23 |
| EL10 | Small electronic components | Examples include low-voltage circuit breakers, overvoltage relays, contactors, contact relays, switches, control or signal switches, connection points, fuses | R26 |

### Material requirements

| Requirements set (relevant component No.) | In regard to test method | Parameter and unit | Maximum or minimum | HL1 | HL2 | HL3 |
|---|---|---|---|---|---|---|
| **R22** (IN16; EL2; EL6A, EL7A; M2) | T01 EN ISO 4589-2: OI | Oxygen content % | Minimum | 28 | 28 | 32 |
| | T10.03 EN ISO 5659-2: 25 kWm$^{-2}$ | $D_S$ max. dimensionless | Maximum | 600 | 300 | 150 |
| | T12 NF X 70-100-1 and -2 600 °C | $CIT_{NLP}$ dimensionless | Maximum | 1.2 | 0.9 | 0.75 |
| **R23** (EX12; EL2; EL5 EL66; EL7B; M3) | T01 EN ISO 4589-2: OI | Oxygen content % | Minimum | 28 | 28 | 32 |
| | T10.03 EN ISO 5659-2: 25 kWm$^{-2}$ | $D_S$ max. dimensionless | Maximum | - | 600 | 300 |
| | T12 NF X 70-100-1 and -2 600 °C | $CIT_{NLP}$ dimensionless | Maximum | - | 1.8 | 1.5 |
| **R24** | T01 EN ISO 4589-2: OI | Oxygen content % | Minimum | 28 | 28 | 32 |
| **R26** (EL10) | T17 EN60695-11-10 | Vertical small burner test | Minimum | V-0 | V-0 | V-0 |



# SELECTED TEST METHODS – AN OVERVIEW

The test methods for plastics in E&E applications can be divided into several categories, and also into tests for evaluating:

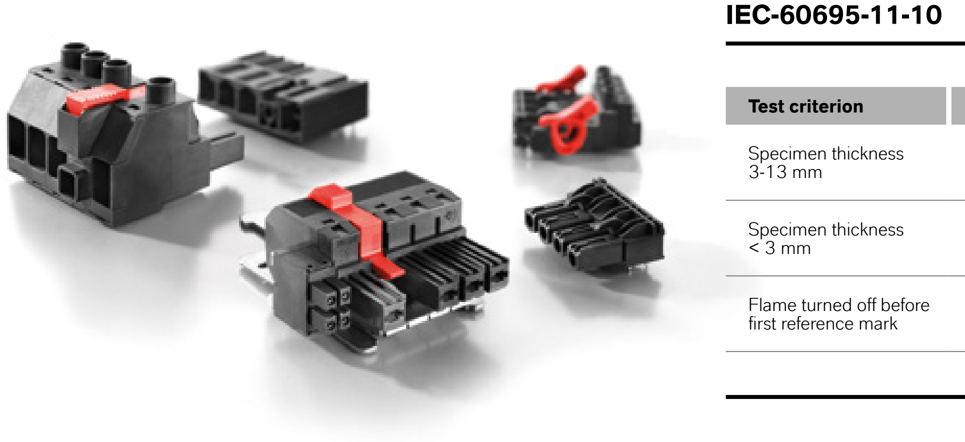
- fire resistance
- electrical safety
- thermal stability and conductivity
- aging resistance and light stability

## Flame retardance tests

The tests for the flame retardance of plastics are oriented to typical parameters of a fire, such as flammability, heat generation and flame propagation. In addition there are tests for safety-related secondary effects of fires, such as smoke production, burning drops of material, and corrosiveness and toxicity of combustion gases and solid fire residues. The most important flame retardance tests for E&E components are specified in the standards of the U.S.-based testing organization Underwriters Laboratories (UL) and the International Electrotechnical Commission (IEC).

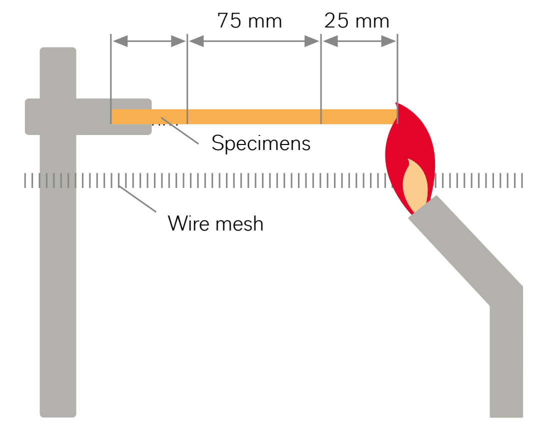
**Tests in accordance with UL 94 – "Tests for Flammability of Plastic Materials for Parts in Devices and Appliances"**

The UL 94[6] regulation specifies test methods for evaluating the flame retardance and fire safety of plastics. The tests correspond to the content of the tests in accordance with DIN IEC 60695-11-10 and -20[5] and CSA C22.2[10] (Canadian Standard Association). The tests evaluate the fire behavior of specimens.



**UL 94 HB test**
The UL 94 HB test (see the graphic) provides information on the extent of the horizontal flame propagation. After test specimens have been stored for 48 hours at 23 °C and 50 percent relative humidity, flame from a Bunsen burner or Tirill burner is applied to them for 30 seconds. The test criterion is the burning rate. One difference compared to IEC 60695-11-10[5] is the HB rating (see the graphic "Classification of the HB test according to IEC-60695-11-10").

**Test rig for UL 94 HB**




| Test criterion | Burning rate | Classification |
|---|---|---|
| Thickness of specimen 3 – 13 mm | ≤ 40 mm/min | HB |
| Thickness of specimen < 3 mm | ≤ 75 mm/min | HB |
| Flame extinguished prior to first gauge mark | 0 mm/min | HB |

**Classification of the HB test according to IEC-60695-11-10**

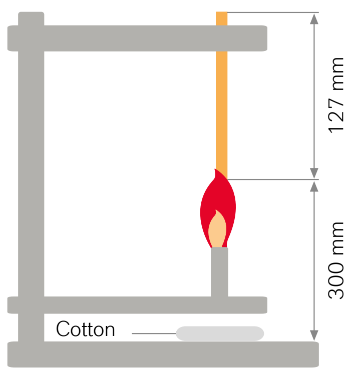
| Test criterion | Burning rate | Rating |
|---|---|---|
| Specimen thickness 3-13 mm | ≤ 40 mm/min | HB40 |
| Specimen thickness < 3 mm | ≤ 75 mm/min | HB75 |
| Flame turned off before first reference mark | 0 mm/min | HB |

# SELECTED TEST METHODS – AN OVERVIEW

**UL 94 V test**

The UL 94 V test (see the graphic) measures the vertical flame propagation and droplet behavior of the specimen. One set of specimen is conditioned for two days at 23 °C and 50 percent relative humidity and a second set for seven days at 70 °C in a hot-air oven. The specimen is supported vertically and a 20-mm-long Tirill burner flame is applied to its lower end for 10 seconds. The burner is removed and the self-extinguishing time of the flame on the specimen is measured. Immediately after that, a flame is applied to the specimen for an additional 10 seconds and the burn duration and glow duration are measured once again. Any ignition of a surgical cotton patch placed below the sample (caused by burning droplets) is evaluated. Depending on the result, a classification is assigned in the Flammability Classes V-0, V-1 or V-2.

**Test rig for UL 94 V**

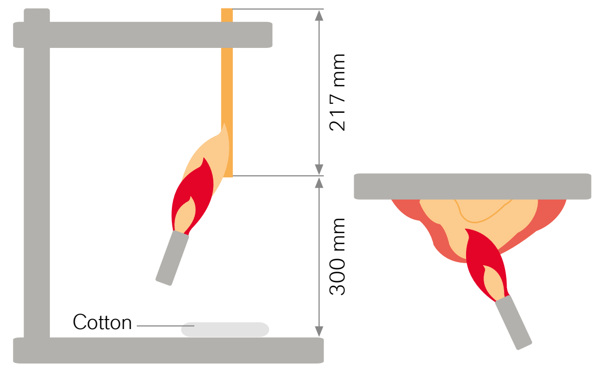



| | V-0 | V-1 | V-2 |
|---|---|---|---|
| Burning time following each flame application | ≤ 10 s | ≤ 30 s | ≤ 30 s |
| Total burning time per set (10 flame applications) | ≤ 50 s | ≤ 250 s | ≤ 250 s |
| Burning down to clamp | no | no | no |
| Burning/glow time following 2nd flame application | ≤ 30 s | ≤ 60 s | ≤ 60 s |
| Ignition of the cotton | no | no | yes |

**UL 94-5V test**

The UL 94-5V test (see the graphic) can be carried out on specimens that have already been classified as V-1 or better in accordance with the UL 94 V test. First, a flame is applied to the vertically aligned specimen 5 times, for 5 seconds each time, and at 5-second intervals. The flame height is 125 mm. If this test is passed, a second test is carried out on a fixed horizontal test plate under the same conditions. If this leads to hole formation in the plate, the test is passed with the classification 5VB. If there is no hole formation, the specimen is classified 5VA.

**Test rig for UL 94-5V**




| | 5VA | 5VB |
|---|---|---|
| Total burning time after 5th flame application | ≤ 60 s | ≤ 60 s |
| Ignition of the cotton | no | no |
| Formation of holes on plaque | no | yes |

**Glow-wire tests in accordance with IEC 60695-2-11 to -13**

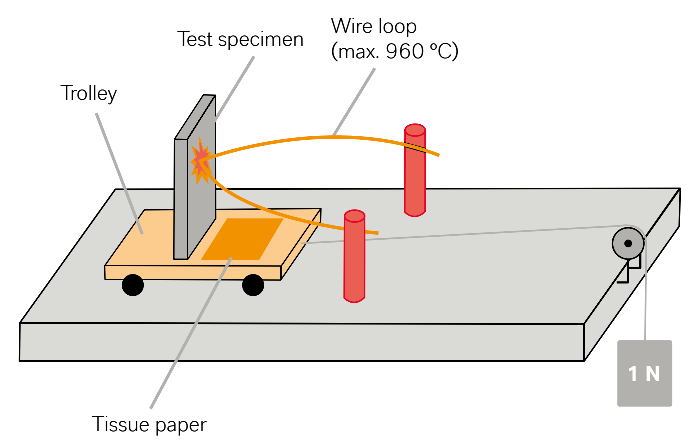
These tests in accordance with IEC 60695-2-11 to -13[4a,b,c] assess the ignition properties of specimens that contact a heated glowing wire, and their afterburn behavior.

With the GWIT test (Glow Wire Ignition Temperature) in accordance with IEC 60695-2-13[4c], the glow wire is applied to specimens in 50 °C increments from 500 to 900 °C, and at 960 °C, for periods of 30 seconds. Ignition is defined as the occurrence of flames for longer than 5 seconds. The GWIT value is expressed as the temperature 25 °C higher than the temperature at which no ignition of the specimen has been observed. It is not acceptable for burning droplets to fall from the specimen.

With the GWFI test (Glow Wire Flammability Index) in accordance with IEC 60695-2-12[4b], the glow wire is applied to specimens in 50 °C increments from 500 to 900 °C, and at 960 °C, for periods of 30 seconds. It is acceptable for the specimen to ignite, but it must self-extinguish within a testing and observation duration of 60 seconds. It is not acceptable for burning droplets to fall from the specimen. The GWFI value is the maximum glow-wire temperature at which the evaluation criteria are fulfilled.

The GWEPT test (Glow Wire End Product Test) in accordance with IEC 60695-2-11[4a] corresponds to the GWFI test, however it is carried out on the finished part.

**Test rig for the Glow Wire test**

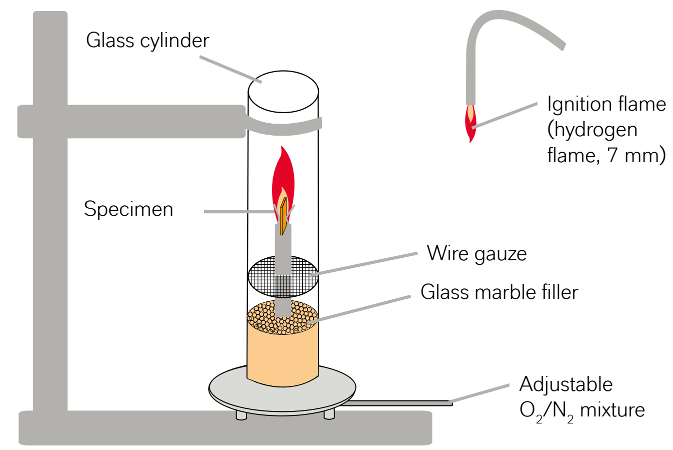



Application time: 30 sec.

**Lowest Oxygen Index test (LOI)**

The Lowest Oxygen Index test (oxygen index, see the graphic) is described in the standards ISO 4589-1[11] and ASTM D 2863 A[12] (American Society for Testing and Materials). It specifies the minimum concentration of oxygen in an oxygen/nitrogen mixture that will support a specimen burning continuously and independently. The LOI value is not listed on the UL Yellow Card and can be found only on the data sheet of the plastic manufacturer.

**Lowest Oxygen Index test (LOI)**



# SELECTED TEST METHODS – AN OVERVIEW

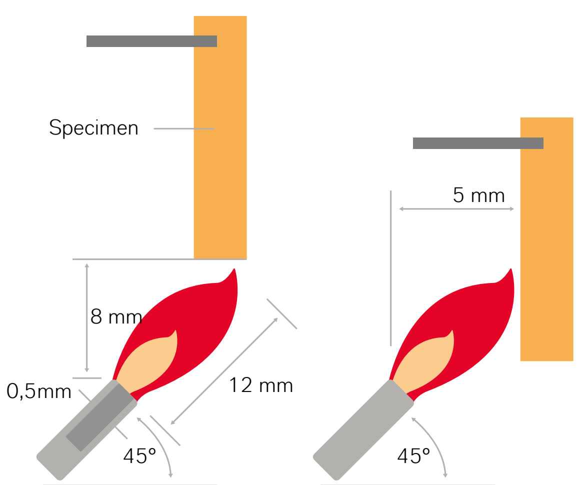
### Needle flame test

The needle flame test in accordance with IEC 60695-11-5[13] (see the graphic) is carried out on the finished part. It recreates the effects of a small flame that could arise due to a malfunction in an electrical device or appliance. This is done by directing a 12-mm-long test flame onto the specimen, generally for 5, 10, 20, 30, 60 or 120 seconds. The test determines the burned distance and afterburn duration. Unless specified otherwise, the needle flame test is passed when

- the specimen does not ignite
- the burn duration is under 30 seconds
- droplets of material or falling, burning particles self-extinguish sufficiently to prevent tissue paper underneath from igniting

For special requirements, the test conditions can be varied and/or made more demanding.

**Needle flame test**

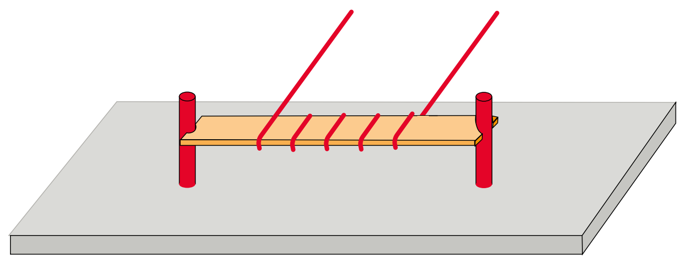



Examples of testing positions

### Hot Wire Ignition test (HWI)

The HWI test in accordance with ASTM D 3874 and IEC 60695-2-20 (see the graphic) simulates a situation where live parts (e.g. wires) are heated through direct contact with the specimen as the result of overload. Resistance wire is wound five times around the specimens at intervals of 6.4 mm. The wire is brought to red heat (approx. 800 °C) using approx. 10 V and 65 watts. The test determines the time (measured in seconds) needed to ignite the specimen. Depending on the ignition time, the specimen is classified in the flammability categories PLC 0 to 5 (Performance Level Categories), in accordance with UL 746A.

**Hot Wire Ignition test (HWI)**

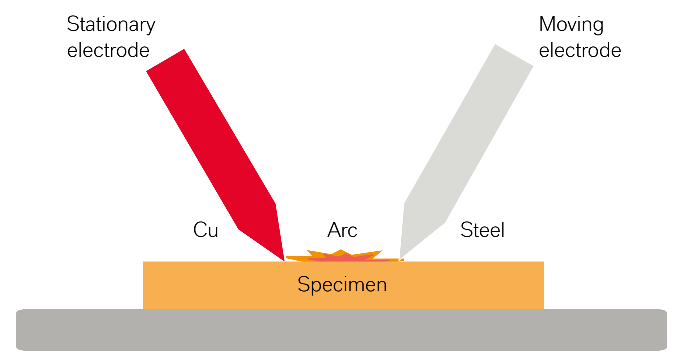


| Time in seconds to ignition | PLC assigned |
|---|---|
| 120 ≤ IT | 0 |
| 60 ≤ IT < 120 | 1 |
| 30 ≤ IT < 60 | 2 |
| 15 ≤ IT < 30 | 3 |
| 7 ≤ IT < 15 | 4 |
| 0 ≤ IT < 7 | 5 |

### High Amp Arc Ignition test (HAI)

The HAI test in accordance with UL 746A[14] (see the graphic) simulates the ignition of plastics through application of electrical arcing. The specimen is positioned between two electrodes and subjected to high-current arcs at regular time intervals. The evaluation criterion is the number of arc exposures required to ignite the specimen. Depending on the number, the specimen is classified in the categories PLC 0 to 4.

**High Amp Arc Ignition test (HAI)**



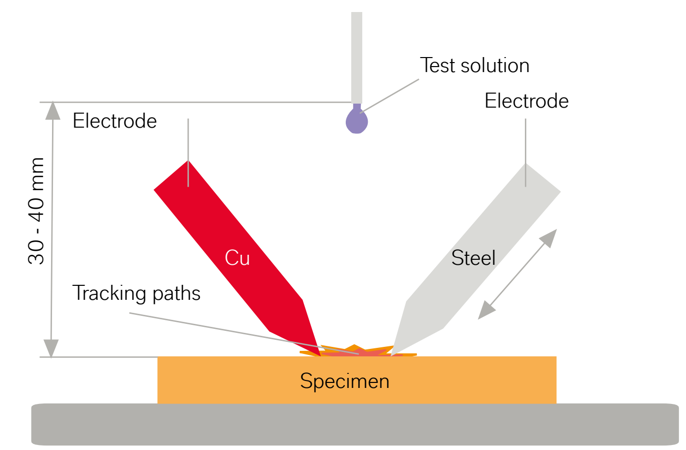

| Number of arcs (NA) required for ignition | PLC assigned |
|---|---|
| 120 ≤ NA | 0 |
| 60 ≤ NA < 120 | 1 |
| 30 ≤ NA < 60 | 2 |
| 15 ≤ NA < 30 | 3 |
| 0 ≤ NA < 15 | 4 |

## Tests of electrical behavior

### Comparative Tracking Index A (CTI A)

The CTI A test in accordance with UL 746A[14] and/or IEC 60112[15] measures the voltage which causes tracking paths. This is done by allowing successive drops of a standard electrolyte testing solution to fall on a specimen placed between two live electrodes (see the graphic). The CTI A is the highest voltage value at which there is no failure after 50 drops have fallen on each of five specimens. In accordance with UL 746A[14], a corresponding, dimensionless PLC classification is assigned to this value. The test sequences in accordance with UL 746A[14] and IEC 60112[15] are comparable, however there are differences in the selection of electrolytes and the assessment of the individual tests. Furthermore, the result is directly specified as the value of the voltage withstood by the specimen.

**Comparative Tracking Index**



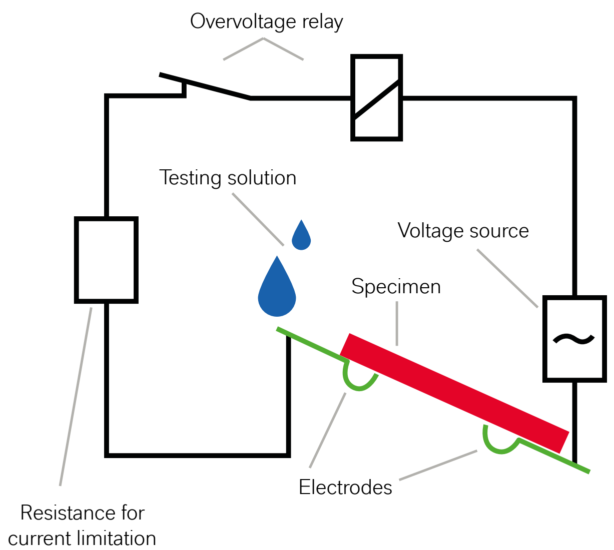

| CTI range Tracking Index (TI) in V | PLC assigned |
|---|---|
| 600 ≤ TI | 0 |
| 400 ≤ TI < 600 | 1 |
| 250 ≤ TI < 400 | 2 |
| 175 ≤ TI < 250 | 3 |
| 100 ≤ TI < 175 | 4 |
| 0 ≤ TI < 100 | 5 |

# SELECTED TEST METHODS – AN OVERVIEW

**Comparative Tracking Index M (CTI M)**
The CTI M test (IEC 60112[15]) is a CTI test version made more stringent than the CTI A test. It also uses a wetting solution that is standardized, but with double the electrical conductivity compared to the CTI A version. A value of CTI-M 300, for example, means that 50 drops of Solution B at less than 300 volts do not cause any leakage current.

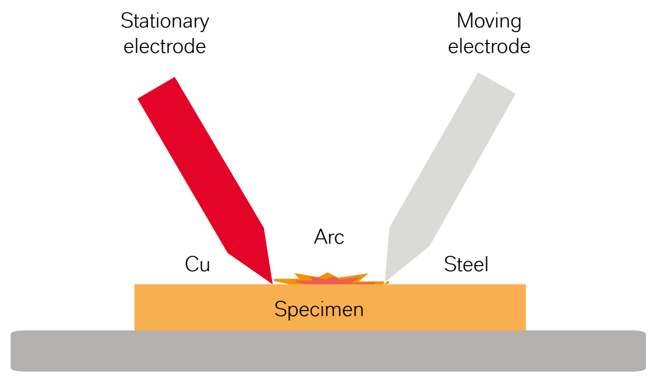
**High-voltage tracking resistance**
The test for high-voltage tracking resistance in accordance with DIN EN 60587 and ASTM D2303[16](see the graphic) recreates how strongly the insulating capacity of a surface changes at higher voltages outdoors when subjected to moisture and soiling. According to UL 746A[14] the testing begins with a test voltage of 1 kilovolt. A specimen is considered to have passed the test if the time-to-track is greater than 60 minutes. If this is the case, the test voltage is increased by 0.5 kilovolt and the test is repeated. The test result is the maximum test voltage at which the time-to-track of 60 minutes is reached with each of five samples. This Inclined-Plane Tracking test (IPT) is entered on the UL Yellow Card.

**Inclined Plane Tracking test**




**High Voltage Arc Tracking Rate test (HVTR)**
The HVTR test (high-voltage tracking rate) in accordance with UL 746A[14] examines the formation and spread of tracking distances on the surface of plastic specimens. Its set-up corresponds to that of the HAI test. High-voltage arcs are ignited on the surface of the specimen for two minutes (see the graphic). The electrodes are moved apart from each other until the arc extinguishes, and then moved closer to each other again once it has extinguished. After the two minutes, the length of the resulting tracking distance is measured and divided by 2. The test result is the rate of speed in mm/min with which a conductive tracking distance forms on the specimen through high voltage. Depending on the rate of speed, the specimen is classified in the categories PLC 0 to 4 in accordance with UL 746A[14].

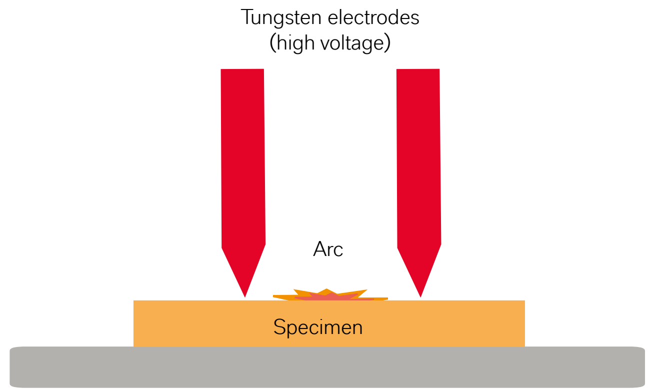
**Test rig for HVTR**




| High Voltage Arc Tracking Rate in mm/min | PLC assigned |
|---|---|
| 0 < TR ≤ 10 | 0 |
| 10 < TR ≤ 25 | 1 |
| 25 < TR ≤ 80 | 2 |
| 80 < TR ≤ 150 | 3 |
| 150 < TR | 4 |

**Arc resistance**
The test of arc resistance in accordance with ASTM D495[17] (see the graphic) investigates the ability of insulating materials to resist an arc at a high voltage but with a weak current in the vicinity of the insulating surface. The purpose of the test is to make a relative distinction between solid electrical insulating materials. A specimen is subjected to a test voltage of 12,500 volts until it ignites, a hole forms, or a conductive tracking path forms. The time it takes for a failure criterion to occur is measured in seconds. Depending on this result, the specimen is classified in the categories PLC 0 to 7 in accordance with UL 746A[14].

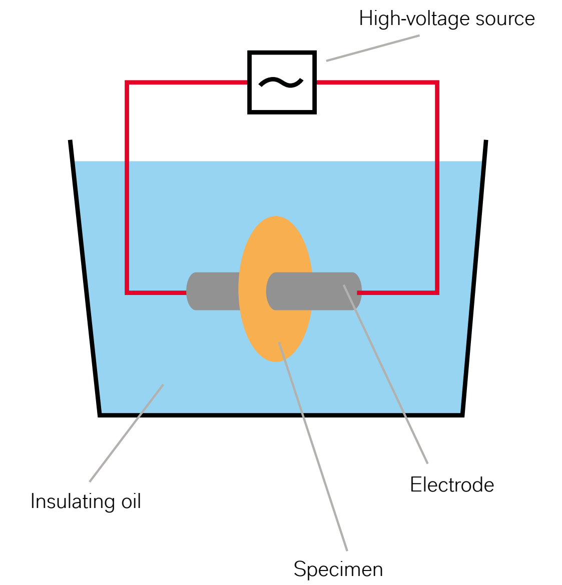
**Test rig for Arc Resistance test**




| Arc Resistance in seconds | PLC assigned |
|---|---|
| ≥ 420 | 0 |
| 360 – 419 | 1 |
| 300 – 359 | 2 |
| 240 – 299 | 3 |
| 180 – 239 | 4 |
| 120 – 179 | 5 |
| 60 – 119 | 6 |
| ≤ 59 | 7 |

**Dielectric strength**
The dielectric strength in accordance with IEC 60243-1[18] and ASTM D149A provides information on the strength of an insulating material in terms of its ability to withstand high voltage. This corresponds to the electric field strength at which the conductivity of an insulator abruptly increases. The voltage is determined (see the graphic) just before the breakdown. The surrounding medium can be air or oil. Because the breakdown voltage depends on the thickness of the specimen, it is divided by this thickness value. The unit of dielectric strength is therefore expressed in kV/mm.

**Dielectric strength**

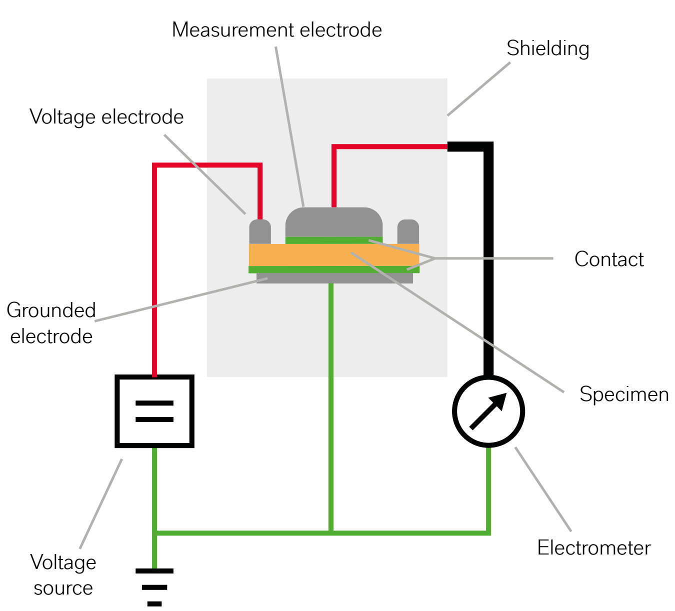


# SELECTED TEST METHODS – AN OVERVIEW

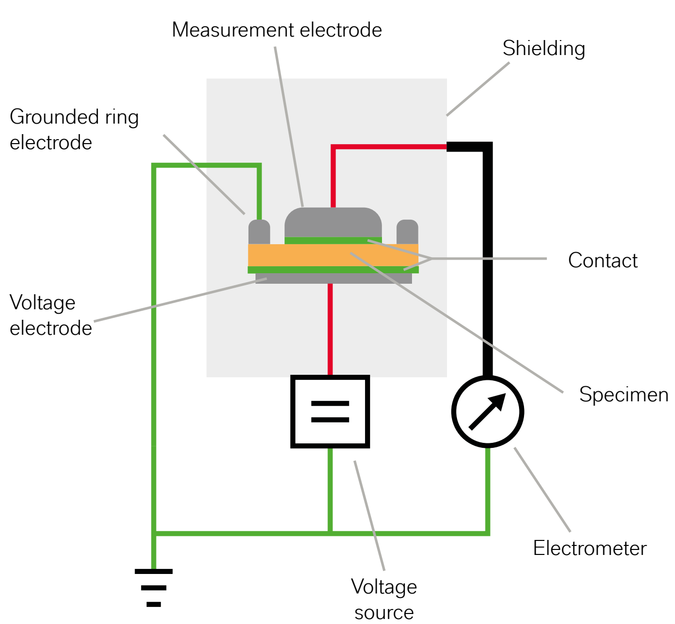
**Surface resistivity**
Surface resistivity is a measure of the strength of current that flows along the surface of an insulating material when voltage is applied to the material and it is in contact with an electrical conductor. It is measured (IEC 60093[19], ASTM D257) by attaching electrodes with standardized dimensions to the surface of a specimen at a defined distance and applying direct current (see the graphic). The surface resistivity corresponds to the ratio of the applied voltage to the current between the electrodes. It is expressed in ohms.

**Volume resistivity**
When a voltage is applied to an insulating material, a current flows; and the current strength depends on the resistance of the insulator. This resistivity (IEC 60093[19], ASTM D257) is determined by using two electrodes to apply a defined voltage to surfaces of a specimen positioned opposite to each other (see the graphic). The volume resistivity is determined on the basis of the measured resistance, which is multiplied by the value for the measured surface and divided by the specimen length. It is expressed in ohm*m. The current along the specimen surface (surface resistivity) is not taken into account.

**Surface resistivity**




**Volume resistivity**




**Relative permittivity**
An insulating material's relative permittivity (formerly referred to as the "dielectric constant") is a dimensionless quantity. It indicates the extent to which an insulating material affects the capacity of a capacitor. Relative permittivity is the ratio of the capacitance of a capacitor using that material as a dielectric, compared to a similar capacitor that has vacuum as its dielectric. The better the material's electrical insulation, the lower the relative permittivity. If a plastic used in AC applications has a low relative permittivity, its molecule fragments will be less susceptible to dipole oscillations. These dipole oscillations, in turn, result in energy losses and/or heat in the plastic, which in electronic components can cause damage or malfunctions.

**Dielectric loss factor**
The dielectric loss factor indicates how much energy an insulation material absorbs in an alternating electrical field and converts into heat loss. In an optimal dielectricum, voltage waveform and current waveform are exactly 90° out of phase. Depending on the insulation material, however, heat losses occur to varying degrees, which is why the current waveform lags behind the voltage waveform. As a result, the phase shift between the current waveform and the voltage waveform becomes less than 90°. The height of this divergence is referred to as the dielectric loss angle. And the tangent of this loss angle is defined as the dielectric loss factor. The smaller the loss factor, the better the dielectric properties of a material. Plastics with a high loss factor are not suitable as insulation materials for high-frequency applications. But they are quite suitable for being joined by means of high-frequency welding, because they quickly become fused through the high heat loss. Relative permittivity and loss factor are measured with the same devices (IEC 60250[20], ASTM D150).

# SELECTED TEST METHODS – AN OVERVIEW

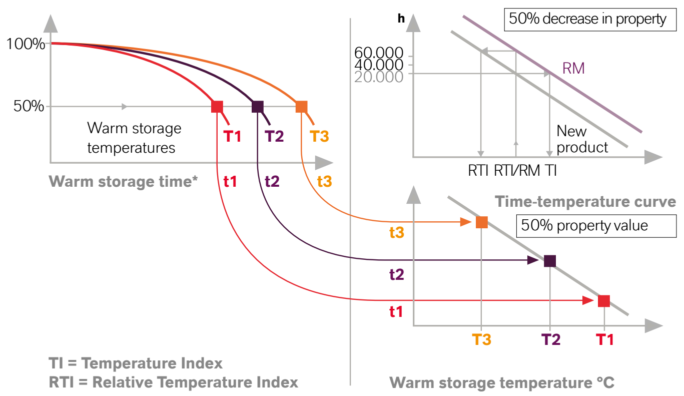
## Tests of long-term thermal resistance

**Relative Temperature Index (RTI)**
The RTI in accordance with UL 746B[21] is a measure of the thermal aging resistance of plastics at high temperatures. It enables conclusions about the maximum service temperature at which a material can still retain key properties within reasonable limits – over long periods and despite the effects of aging. The aging is normally determined in relation to a reference material. The tests determine the temperature at which the observed property has diminished to 50 percent of its initial value after heat aging (see the graphic).

**THE FOLLOWING ARE RTIS DEFINED FOR SPECIFIC PROPERTIES:**

- **RTI Elec (electrical load):** dielectric strength
- **RTI Str (mechanical load without impact):** preferably tensile strength, otherwise flexural strength
- **RTI Imp (mechanical load with impact):** primarily critical impact resistance, in some cases also other tests, e.g. impact strength

**Relative Temperature Index (RTI)**



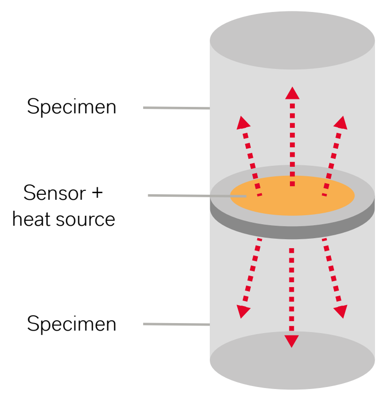

**Temperature Index (TI)**
The TIs in accordance with IEC 60216-1[22] are a measure of the continuous service temperature at which critical properties of a material (electrical insulation, strength, toughness) still remain within an acceptable range (50 percent criterion after 5,000 or 20,000 hours) despite aging.

## Determining thermal conductivity and diffusivity

The principles of methods for determining thermal conductivity and diffusivity of plastics are described in standards including DIN EN ISO 22007[23]. There are stationary methods that subject a specimen to an uninterrupted flow of heat, and also transient measurement techniques that examine the chronological sequence of a heat flow. The specimens also vary depending on the specific method used. Practical experience has shown that when different methods are used, it is difficult to compare certain resulting thermal conductivity properties. Furthermore, the measurement of a specimen's thermal conductivity provides only qualitative findings regarding the thermal conductivity of the component for which the material may be intended.

**Hot disk method**
With the hot disk method (also known as the hot wire method), a heating element with temperature sensors is placed between two identical specimens to observe the spatial and chronological diffusion of a heat pulse. The flow of heat penetrates uniformly in all spatial directions. Therefore the calculation of the thermal conductivity results in an integral value. The method offers the advantage that it is not only quick and easy to use, but also suitable for many geometries. The specimen geometry has not been standardized.

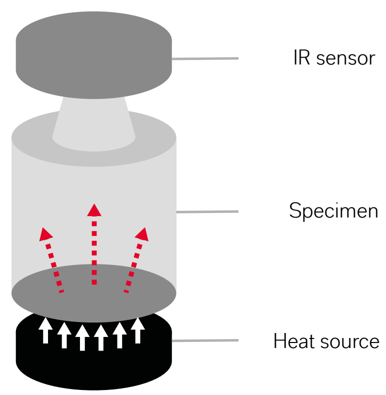
**Hot wire method ("hot disk")**




**Heat flow in 3 directions → integral value**

**Laser flash method**
The laser flash method allows directional measurement of thermal conductivity. A specimen is placed between a flash lamp (the heat source) and an infrared detector. After discharge of an energy pulse (usually a xenon flash lamp), the temperature increase on the facing side of the specimen is monitored and the directional thermal diffusivity is determined. Once the heat capacity has been measured against a reference, this measurement serves as the basis for calculating the thermal conductivity. Preparation of the specimen for the laser flash method can entail high costs.

**Laser flash method**




**Heat flow in 1 direction → directional value**

## Determining reflectivity

Reflectivity (also called "reflectance" and "degree of reflection") indicates what percentage of light that falls on an object is reflected. This involves differentiating between specular reflection, diffuse reflection, and the mixed reflection made up of both of these proportions. The reflectivity depends on the wavelength. As a rule, it is determined photometrically in accordance with DIN 503624, e.g. with a sphere-type spectrophotometer. By means of numerical gloss control, the measurement data can be recorded either including gloss or excluding gloss. In addition to the L*a*b* color space, the reflection of the incident light can be determined wavelength-dependent. The proportion of the reflected light on the surface of the plastic also enables conclusions about the absorption behavior of the surface. A particularly important factor here is the high-energy UV component of the light. It can lead to degradation of the polymer matrix, resulting in aging (yellowing) of the plastic. This must be taken into account with plastics for reflectors of LED lamps, for example.

# FLAME RETARDANTS AND FIRE PROTECTION – AN OVERVIEW

In Polyamide 6, polyamide 66 and PBT are frequently used in the electrical and electronics industry to insulate live parts. To ensure fire safety, in most cases this means they are required to contain flame retardants, which have the property of being able to reduce the flammability of materials and the speed of flame propagation. Most are based on chemical substances that contain the elements bromine, chlorine, phosphorus and nitrogen, and are compounded with the polymer matrix. Their modes of action, advantages and disadvantages are very varied, so in this section we present the most important flame retardants for polyamide 6, polyamide 66 and PBT.

**Halogenated flame retardants**
**Area of effect 1 (see the graphic)**
Bromine and chlorine are present in these flame retardants as organic halogen compounds. Halogen radicals are produced in a fire, and they intercept the energy-rich hydrogen and hydroxyl radicals in the flame, extracting its energy. Advantages of halogenated flame retardants are their efficient flame retardance and good compounding properties. A disadvantage is that they produce toxic and corrosive gases in a fire. They are therefore less suitable for applications that require low toxicity of smoke gases.

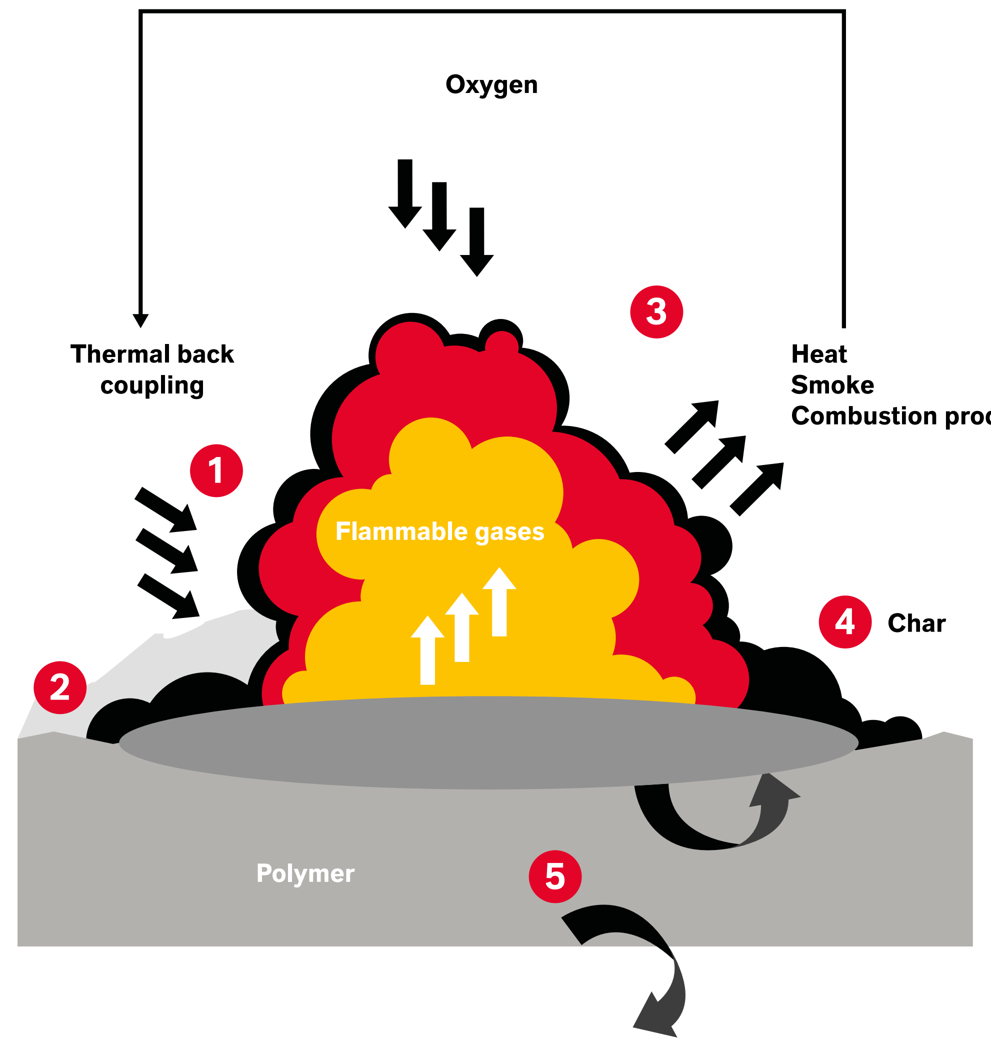
**Phosphorous-based flame retardants**
**Area of effect 4 (see the graphic)**
Phosphorous is compounded in the plastic either as inorganic red phosphorus or as an organic phosphorus compound. In a fire, organic phosphorus compounds produce phosphorus oxides, which remove water from the substrate, thus charring the polymer matrix. The carbon char layer separates the flame from the polymer, taking away its "nourishment." Red phosphorus has a similar effect. Organic phosphorus compounds are often used together with nitrogen-based substances that cause a foaming of the matrix (intumescence), which impedes the ingress of oxygen and heat. In addition, phosphorus acts as a radical scavenger in the gas phase, like halogenated flame retardants. Processing of red phosphorus can produce corrosive gases. And its inherent color limits its use to dark-colored applications. Organic phosphorus compounds are significantly less corrosive and do not restrict coloring options, but the processing window of the plastics compounded with it is smaller.

**Inorganic flame retardants**
**Area of effect 3 (see the graphic)**
Inorganic flame retardants such as magnesium hydroxide (MDH) split off water when consuming energy. As a result, the matrix cools and the combustion gases are diluted with water. They display very minimal secondary effects of fire, such as smoke gas toxicity and smoke gas density, however they influence the mechanical and rheological properties of the compounds.

**Nitrogen-based flame retardants**
**Areas of effect 2, 3 and 5 (see the graphic)**
Nitrogen-based flame retardants produce their effect by means of various mechanisms. They decompose when subjected to heat, for instance, which serves to draw off energy from the flame area. And gases are produced that allow foaming of the matrix, which impedes the ingress of oxygen and heat. If the flame retardant also contains phosphorus, a flame-inhibiting carbon char layer forms. Furthermore, a matrix depolymerization can occur, so that the matrix draws away from the heat source. Nitrogen-based flame retardants are less effective in reinforced compounds, but they are easy to process in most cases.

**Mode of action of flame retardants**

The diagram shows in summary form, how and where flame retardants act.




1 **Radical recombination**
Halogenated FR additives

2 **Intumescence**
Foam produced by intumescence system (blowing agent)

3 **Fire inhibiting gases**
Decomposition of water from minerals as $Mg(OH)_2$
Decomposition of $N_2/NH_3$ from melamine cyanurate

4 **Surface passivation**
Char formation by phosphoric acid or red phosphorous

5 **Matrix depolymerisation**
Depolymerisation induced by FR system

# OUR THERMOPLASTICS

Our range of plastics covers a very wide spectrum of properties. It encompasses polyamide 6 and polyamide 66 compounds of the Durethan® brand, PBT compounds of the Pocan® brand, and compounds based on polycyclohexylene dimethylene terephthalate (PCT).

The fundamental strengths of the Durethan® polyamides include not only their excellent mechanical strength and stiffness, but also good electrical insulation properties, high resistance to heat and chemicals, low friction, good emergency running properties, wear resistance and very good attenuation of noise and vibration.

Pocan® is very heat-resistant, absorbs very little moisture, and displays good electrical insulation properties, outstanding strength and hardness, and excellent slip properties. In addition it features good resistance to chemicals, impressive abrasion resistance and low susceptibility to stress cracking.

The properties of the PCT-based compounds are similar to those of Pocan but considerably more heat-resistant.

## The product range for the E&E industry

Our portfolio of compounds for the E&E industry covers a broad spectrum. It also features numerous flame-retardant material variants distinguished by superior flame retardance, good electrical values, excellent flowability, and very good mechanical properties.

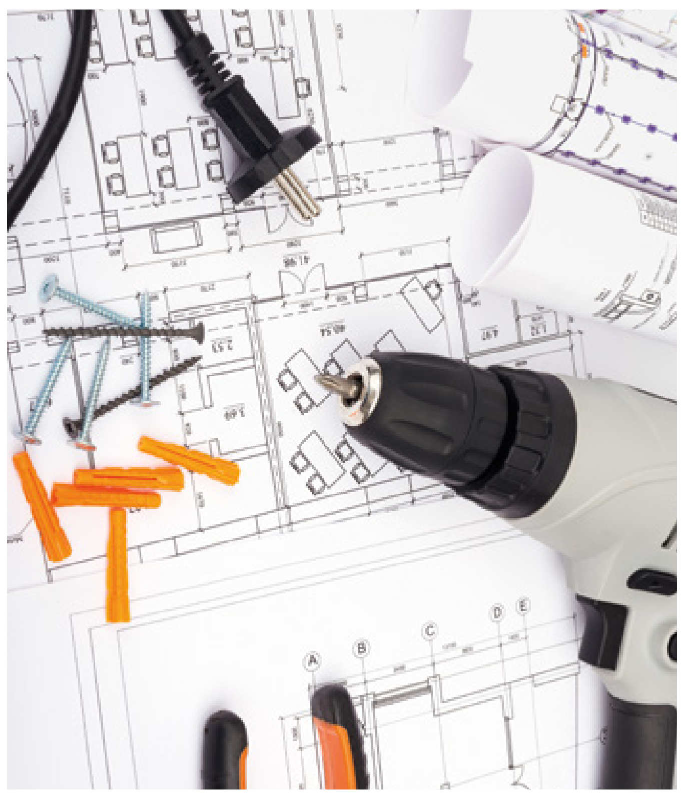
All of our products are in compliance with the EU directives WEEE (Waste Electrical and Electronic Equipment) and RoHS (Restriction of the Use of certain Hazardous Substances in Electrical and Electronic Equipment), as well as the European Union's REACH regulation (Registration, Evaluation and Authorisation of Chemicals, VO (EG) No. 1907/2006). Most of the flame-retardant materials fulfill the fire protection requirements and/or glow-wire tests (GWIT, GWFI) of the household appliances standard IEC 60335-1[3].

**Our range for injection molding and extrusion of E&E components includes:**

- non-reinforced compounds and fiber-, mineral- and/or glass-bead-reinforced compounds
- products with halogenated or halogen-free flame-retardant packages
- flame-retardant materials that produce very little smoke in the event of fire
- products with outstanding flowability
- highly reinforced materials for very strong and stiff components
- materials with low susceptibility to corrosion
- materials with excellent color stability in hot-air aging tests

**Examples of the latest developments include:**

- compounds with high resistance to LED light
- light-stable and lead-free polyester suitable for vapor phase soldering, with excellent light reflection
- materials with excellent thermal conductivity
- polyamides with extraordinary temperature stability
- product grades that are flame-retardant but also display very low warpage and are heat-resistant and weather-resistant
- laser-transparent configurations for laser radiation welding



## Selected innovative materials

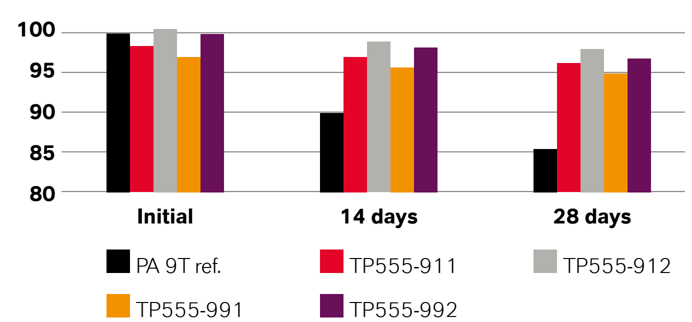
In this section we present a selection of the latest innovative materials that underscore our expertise as a partner of the E&E industry.

**PCT compounds: good light reflection, light-stable and lead-free, suitable for vapor phase soldering**

We are offering four new PCT compounds specially developed for housings and sockets of LED chips, in mineral-reinforced and/or glass-fiber-reinforced variants. Their light reflection is very high, ranging from 93 percent to nearly 96 percent (450 nm). Used as a material for LED housings, they reflect the light of the LEDs almost completely, keeping brightness losses to a minimum. Their good reflection behavior is retained to a great degree over time under LED use conditions. That is in contrast to high-melting polyamides, for example, which yellow from exposure to heat and light, causing their light reflection and thus the brightness of the LEDs to diminish noticeably.

- The properties of the four new PCT compounds are tailored for use in housings, sockets and other LED chip components. As a material for housings they reflect the LED light almost completely, so there are hardly any brightness losses.

**LED chip material after hot storage at 120 °C**




- Even after 28 days in storage at 120 °C, the light reflection of Pocan TP555-911, -991, -912 and -992 is still far above 90 percent. In contrast, the reflection of high-melting polyamides diminishes noticeably, because they yellow with age.

# OUR THERMOPLASTICS

**Pocan® AF4110:**
**Extremely low warpage, excellent flame retardance and color stability**
Reinforced with a glass fiber content of 12 percent, the flame-retardant blend of PBT and ASA (acrylic ester-styrene-acrylonitrile) displays extremely low warpage and excellent flame retardance. Subjected to tests in accordance with UL 94, it attained the best classification V-0 (0.4 mm). It results in good surfaces that are very low in emissions (VDA 278). Due to its excellent resistance to light and moisture, in applications it fulfills weathering tests in accordance with ISO 4892-3. This eliminates any need for the components to have separate, costly UV protective coatings. Like its "siblings" with 20 or 30 percent glass fiber content, the material is suitable for applications including battery cell housings, plug connectors that are subject to mechanical loads, and large, geometrically complex housings for electronic circuits such as battery management systems.

**Durethan® BG30XXF, BG30XH2.0XF und H3.0XF:**
**Minimal warpage, excellent flowability**
The three polyamide 6 compounds are reinforced with a 30 percent mix of glass fibers and glass microbeads. Their strong points include not only outstanding flowability, but also exceptionally low susceptibility to warpage. Featuring a good mechanical property profile, their flowability is more than 30 percent higher than that of Durethan® BG30X, a similar standard polyamide 6. The compound with H3.0 thermostabilization has very low copper and halide content and is customized for natural-colored and light-colored applications in electrical engineering and electronics, such as plugs, plug connectors and fuse boxes. The H2.0 material version is intended for components that are colored black and subjected to higher heat loads.

**Pocan® B1205XF:**
**Tailored for miniaturization**
Our wide range of easy-flowing Pocan® XF polyester compounds includes both reinforced and non-reinforced grades such as Pocan® B1205XF. Thanks to its outstanding flowability, this material is perfect for the trend toward miniaturization in the electrical and electronics industry. It is ideal for complex components with extremely thin wall thicknesses, such as mini-plugs. Compared to similar standard grades, the compound is more resistant to hydrolysis and exhibits a lower density, which means processors can save on material.

**Pocan® BF4232HR:**
**Hydrolysis-stable and flame-retardant**
Reinforced with a 30 percent glass fiber content, the PBT is a new product for safety-related E&E components that must remain functional in a hot and moist environment. Along with excellent hydrolysis stability, it displays outstanding flame retardance and passes the UL 94 test with the best classification of V-0 (0.4 mm). It achieves this excellent classification in all colors required for the test, which is the exception rather than the rule for materials of this type.

**Durethan® BKV25FN27:**
**Material of choice for circuit breakers**
This halogen-free, flame-retardant polyamide 6 is an alternative to mineral-filled halogen-free polyamide 6 grades for use in production of circuit breakers for low-voltage applications. The glass-fiber-reinforced material offers high mechanical strength and thermal stability. Components made of it can well withstand the enormous mechanical stresses and high temperature peaks that occur during a short circuit. It also meets the requirements for circuit breakers in higher performance classes (rated currents). The compound is classified in accordance with UL 94 V-2 (0.75 mm), and it achieved the best possible GWFI (Glow Wire Flammability Index) value for plastics (960 °C) for a component with wall thicknesses of less than 1 mm. The excellent heat resistance is confirmed by an HDT A value (ISO 75-1,-2) of 155 °C.

**Durethan® XTS3:**
**Long-term resistance up to 200 °C**
With XTS3 (Xtreme Temperature Stabilization) we have developed another high-tech heat stabilizing system for Durethan®. Like the XTS1 system already launched on the market, it raises the continuous service temperatures that polyamides 6 and 66 can withstand by around 60 °C, to approximately 200 °C. The heat stabilization is based not on an inorganic additive system, but on an organic one instead. And Durethan® material variants that feature this stabilizer system are particularly suitable for plastic parts that are subjected to high thermal loads and come into direct contact with metal components. That's because the metal- and salt-free stabilization ensures there is no contact corrosion. Possible applications in the E&E sector are housing parts, plug connectors and plug strips.

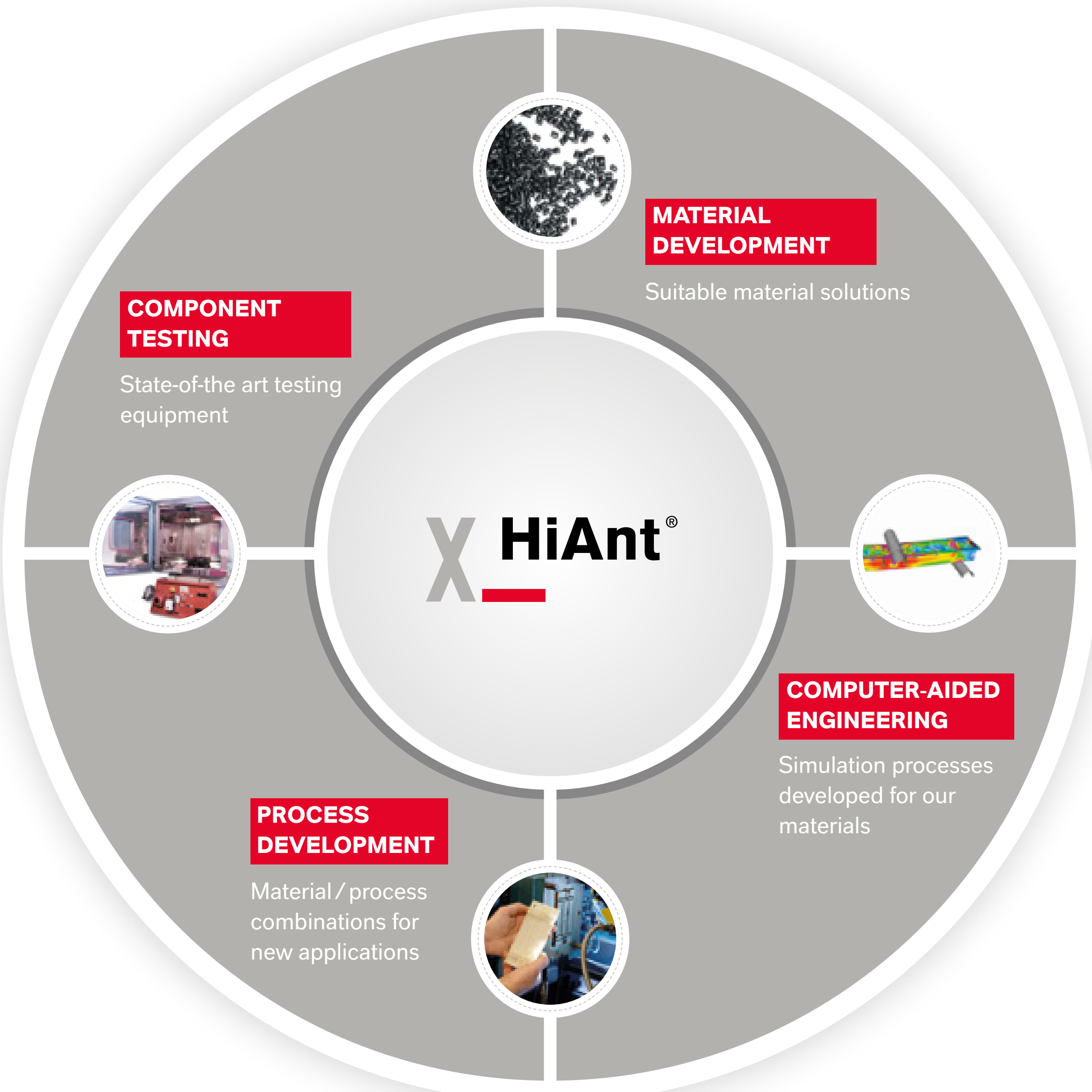
**Pocan® BFN:**
**Comparable to halogenated PBT compounds**
Reinforced PBT compounds with halogen-free flame retardance are in demand for reasons including ecological concerns. With this in mind, we have expanded our Pocan® PBT family to include new material variants that feature glass-fiber reinforcement contents of 13 percent, 20 percent and 25 percent, as well as organic phosphorus flame retardant packages. The compounds are as easy to process in a broad process window as comparable halogen-containing products and are also at least equivalent in terms of flame retardance, heat stability and shrinkage. And they offer very significant advantages with regard to tracking resistance, laser marking, color stability and density. The tracking resistance of Pocan® BFN4231, for example, achieves a CTI A value (UL 746A-14) of 600 V (PLC 0 on the UL Yellow Card). Because the flame retardant package is free of red phosphorus, Pocan® BFN is not susceptible to corrosion when in contact with metals.

**High-modulus thermoplastics: Replacing metal**
Manufacturers of household appliances, in particular, are increasingly trying to replace metal with thermoplastics. This is because thermoplastics offer advantages including greater design freedom and the possibility of cost-saving integration of functions by means of injection molding. Here, we offer a wide range of polyamide and PBT compounds with glass fiber content as high as 60 percent, which are outstanding in terms of their good melt flow rates and excellent levels of strength and stiffness. Polyamide 6 and polyamide 66 variants in the Durethan® range that are reinforced with a glass fiber content of 60 percent, for example, achieve tensile modulus values of over 13,000 MPa (conditioned).

# HIANT® – CUSTOM SERVICES FOR THE E&E INDUSTRY

The goal of our HiAnt® services is to collaborate with customers around the world on the development of intelligent and innovative system solutions in the areas of materials, applications, processing methods and technologies. HiAnt® spans the entire development chain of a component. Examples of selected services relevant for the E&E industry include:

- experiments on corrosion behavior of flame retardant additives upon contact with metals
- standards-compliant performance of important flame retardance tests
- provision of angle-resolved BRDF data (Bidirectional Reflectance Distribution Function) for projects
- Technical Service Center facilities for experiments with laser marking in a wide variety of colors
- Technical Service Center facilities for joining experiments using ultrasonic, vibration and IR welding, for optimizing production processes and materials
- filling analyses for purposes including the positioning of sprues and detecting weld lines and air pockets
- calculations related to warping and to design of the tool cooling system
- in the case of materials displaying anisotropic thermal conductivity, filling simulations for determining local orientation of fillers, to calculate the directional dependency of thermal conductivity in a component
- a simulation tool that helps to design heat-dissipating plastic components by taking into account the part geometry, installation situation, heat input and air convection in the component's immediate proximity




# LIST OF IMPORTANT STANDARDS

1 **UL 746C** "Standard for Polymeric Materials - Use in Electrical Equipment Evaluations"

2 **DIN EN 60664-1** "Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests"

3 **DIN EN 60335-1** "Household and similar electrical appliances. Safety – Part 1: General requirements"

4a **IEC 60695-2-11** "Fire hazard testing – Part 2-11: Glowing/hot-wire based test methods – Glow-wire flammability test method for end-products (GWEPT)"

4b **IEC 60695-2-12** "Fire hazard testing – Part 2-12: Glowing/hot-wire based test methods – Glow-wire flammability test method for materials (GWFI)"

4c **IEC 60695-2-13** "Fire hazard testing – Part 2-13: Glowing/hot-wire based test methods – Glow-wire ignition temperature test method for materials (GWIT)"

5 **DIN EN 60695-11-10** "Fire hazard testing – Part 11-10: Test flames – 50 W horizontal and vertical flame test methods"

6 **UL94** "Tests for Flammability of Plastic Materials for Parts in Devices and Appliances"

7a **EN 45545-1** "Railway applications - Fire protection on railway vehicles - Part 1: General"

7b **DIN EN 45545-2** "Railway applications - Fire protection on railway vehicles - Part 2: Requirements for fire behavior of materials and components"

8 **DIN EN ISO 5659-2** "Plastics - Smoke generation - Part 2: Determination of optical density by a single-chamber test "

9 **NF X70-100** "Fire tests – Analysis of gaseous effluents – Part 2: Tubular furnace thermal degradation method"

10 **CSA C22.2 / No. 0.17-92** "Evaluation of Properties of Polymeric Materials – General Requirements; Part 4: Flame Test Procedure"

11 **ISO 4589-1** "Plastics -- Determination of burning behavior by oxygen index -- Part 1: Guidance"

12 **ASTM D 2863** "Standard test method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index)"

13 **DIN EN 60695-11-5** "Fire hazard testing – Part 11-5: Test flames - Needle-flame test method - Apparatus, confirmatory test arrangement and guidance"

14 **UL 746A** "Polymeric Materials – Short Term Property Evaluations"

15 **DIN EN 60112** "Method for the determination of the proof and the comparative tracking indices of solid insulating materials"

16 **ASTM D 2303** "Standard Test Methods for Liquid-Contaminant, Inclined-Plane Tracking and Erosion of Insulating Materials"

17 **ASTM D 495** "Standard Test Method for High-Voltage, Low Current, Dry Arc Resistance of Solid Electrical Insulation"

18 **DIN EN 60243-1** "Electric strength of insulating materials - Test methods - Part 1: Tests at power frequencies"

19 **DIN IEC 60093** "Methods of test for insulating materials for electrical purposes; volume resistivity and surface resistivity of solid electrical insulating materials"

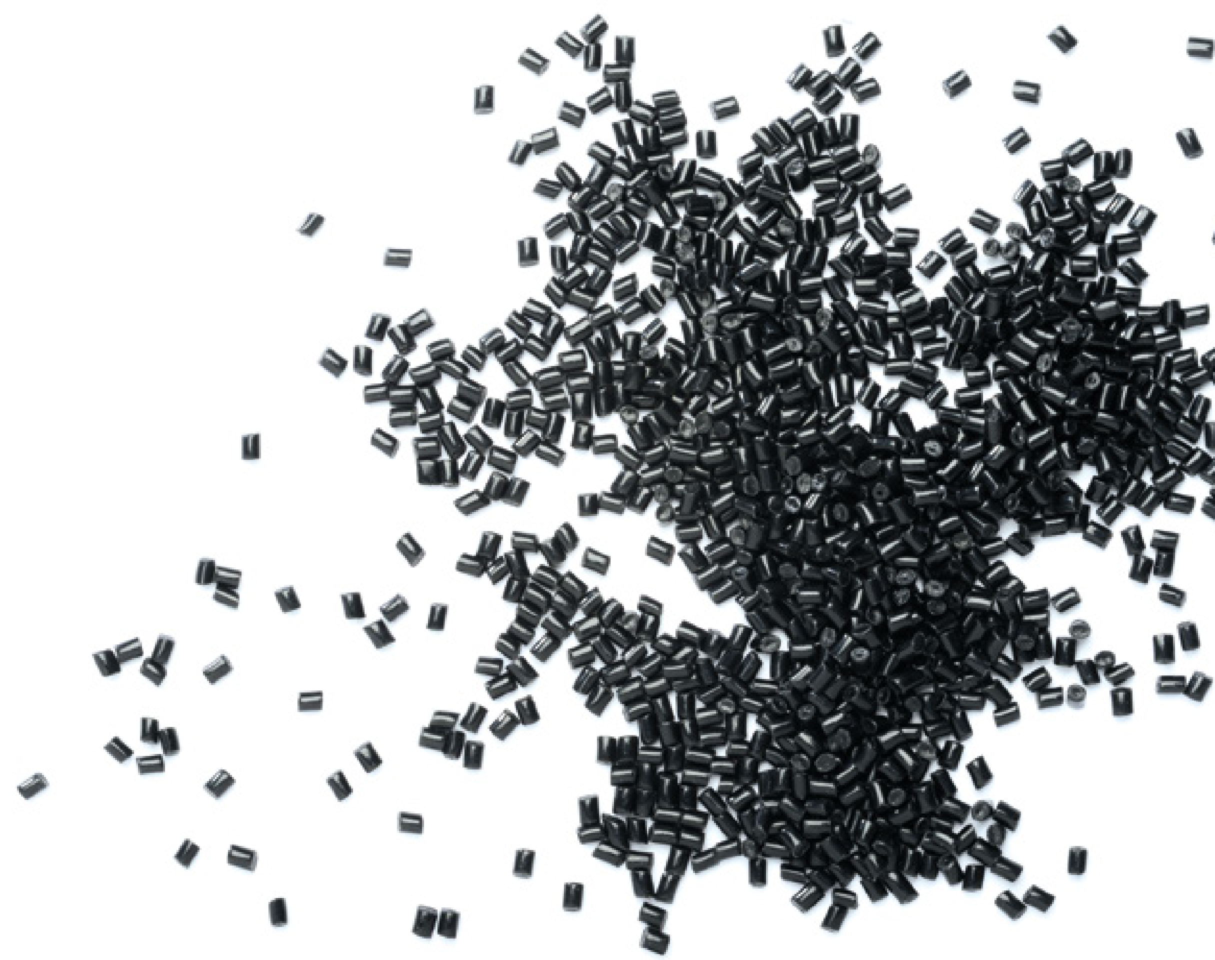
20 **IEC 60250** "Recommended methods for the determination of the permittivity and dielectric dissipation factor of electrical insulating materials at power, audio and radio frequencies including meter wavelengths"

21 **UL 746B** "Polymeric Materials – Long Term Property Evaluations"

22 **IEC 60216-1** "Electrical insulating materials - Properties of thermal endurance – Part 1: Aging procedures and evaluation of test results"

23 **DIN EN ISO 22007** "Plastics -- Determination of thermal conductivity and thermal diffusivity – Part 1: General principles (ISO 22007-1:2009); German version EN ISO 22007-1:2012"

24 **DIN 5036** "Radiometric and photometric properties of materials; methods of measurement for photometric and spectral radiometric characteristics"



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