BASF

We create chemistry

Engineering plastics for the E&E industry

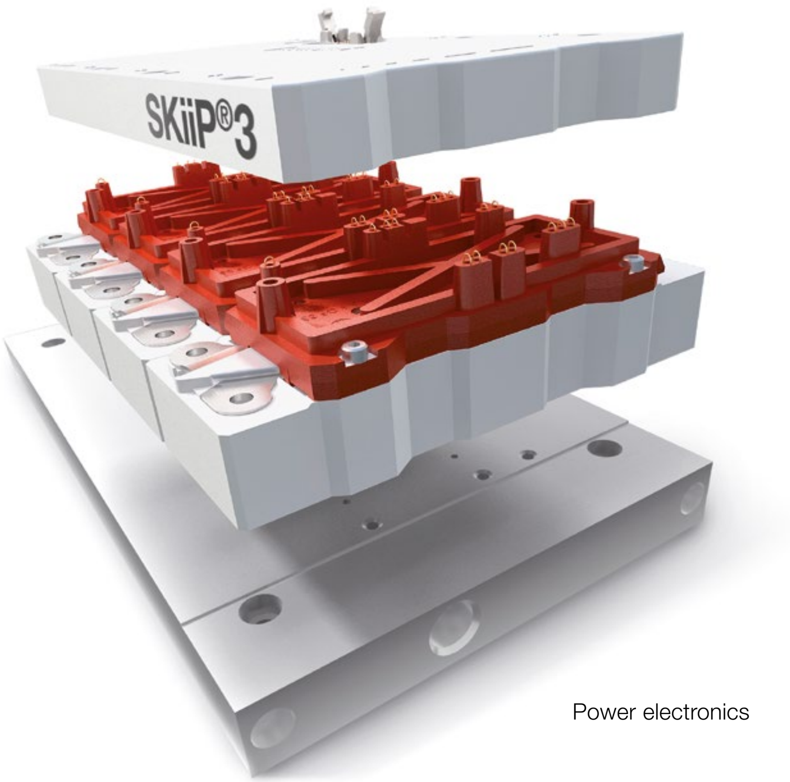
Standards and ratings

Engineering plastics for the E&E industry

Competence in fire safety

We hardly notice it any more, but we are living in the era of plastics. Thanks to their multifaceted application possibilities, plastics have become an indispensable fixture of modern life. They make tremendous contributions to our quality of life and comfort, to technology and progress, to esthetics and to our well-being. Plastics – key materials in our daily lives – are flammable materials, like most natural substances.

Fires cause extensive damage to people, property and the environment throughout the world. Important safety aspects in case of fire are precautionary measures that allow early fire detection and fire-fighting and provide possibilities for escape and evacuation. Moreover, certain safety requirements apply in terms of the fire behavior of the materials employed and of the articles made of them, always as a function of the actual conditions of use. Such requirements often differ in the various areas of application and cannot be directly compared to each other. However, all of them share the overriding objective of protecting the lives and health of people as well as property and the environment.



Power electronics

In a joint effort with users and many organizations involved in fire safety, BASF is providing the necessary prerequisites for the safe and reliable utilization of its products. For instance, the fire-retardant Ultramid® and Ultradur® grades (PA and PBT, respectively) were developed paying close attention to the aspects of product and application development, the environment and the market. Through BASF's participation in fire-safety commissions, new material-related requirements are recognized at an early point in time and implemented accordingly.

The present brochure is intended to give users of BASF's engineering plastics an overview of the numerous fire-safety requirements and test stipulations in the most important technical areas of application, particularly in the transit sector and in electrotechnical applications. This overview cannot be complete. Thus, for example, it does not deal with applications having to do with the construction sector, shipbuilding, packaging or consumer products such as furniture, textiles or toys.

BASF experts will always be glad to provide assistance in case of specific, more in-depth questions, also regarding the topics that have not been dealt with here.


DAkkS Deutsche Akkreditierungsstelle

Deutsche Akkreditierungsstelle GmbH

Entrusted according to Section 8 subsection1 AkkStelleG in connection with Section 1 subsection 1 AkkStelleGBV
Signatory to the Multilateral Agreements of EA, ILAC and IAF for Mutual Recognition

Accreditation

The Deutsche Akkreditierungsstelle GmbH attests that the testing laboratory

BASF SE
Carl-Bosch-Straße 38, 67056 Ludwigshafen

for the testing laboratory

BASF SE,
E-PME/NQ-H201
67056 Ludwigshafen

is competent under the terms of DIN EN ISO/IEC 17025:2005 to carry out tests in the following fields:

physical, mechanical and technological, environment and fire testing of plastics and textiles

The accreditation certificate shall only apply in connection with the notice of accreditation of 15.04.2015 with the accreditation number D-PL-14121-04 and is valid until 14.04.2020. It comprises the cover sheet, the reverse side of the cover sheet and the following annex with a total of 8 pages.

Registration number of the certificate: D-PL-14121-04-00

Berlin, 28.05.2015

signed Ralf Egner
Head of Division

This document is a translation. The definitive version is the original German accreditation certificate.

Fig. 1: Accredited BASF test laboratory in accordance with **DIN EN ISO/IEC 17025**[1]

Description of the fire behavior

Principles: ignition and fire development

The start of a fire and its spread are determined primarily by the size, type and position of the source of ignition as well as by the form and specific properties of the flammable material. The combination with other materials as well as the production and ambient conditions also influence the fire behavior.

A fire often develops according to certain patterns. Seekamp[2] and Becker[3] have extensively studied and described fire incidents in rooms:

After the flammable product has ignited, the flames normally spread in the form of fire appearing on the outer surface of the product. Once the initially ignited material has generated enough heat, additional areas are affected by the fire.

The fire spreads even more quickly whenever more heat is generated that elevates the room temperature and, through heat radiation, heats up and destroys the material surfaces that are close to the fire (phase of the starting fire). After a certain time, the gases released in this process reach ignitable concentrations, so that the fire can abruptly engulf the entire room. This flash-over marks the beginning of the fully developed fire. The spread of the fire to zones outside of the room depends on the fire resistance of the structural elements surrounding the room (Fig. 2).

Once the fire has passed its peak in the room, the phase of the sub-siding fire starts, during which the flammable materials in the room burn out more or less completely.

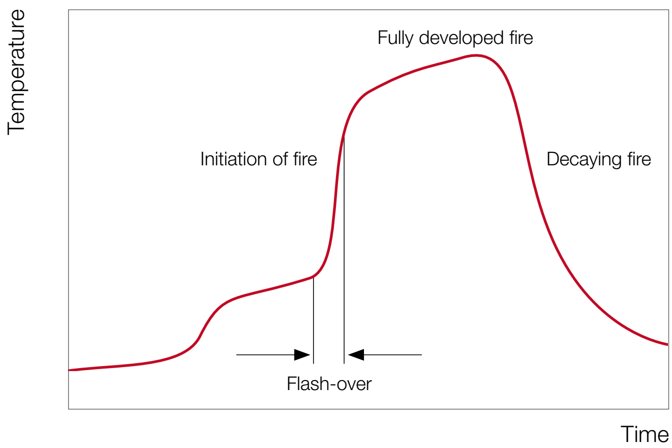
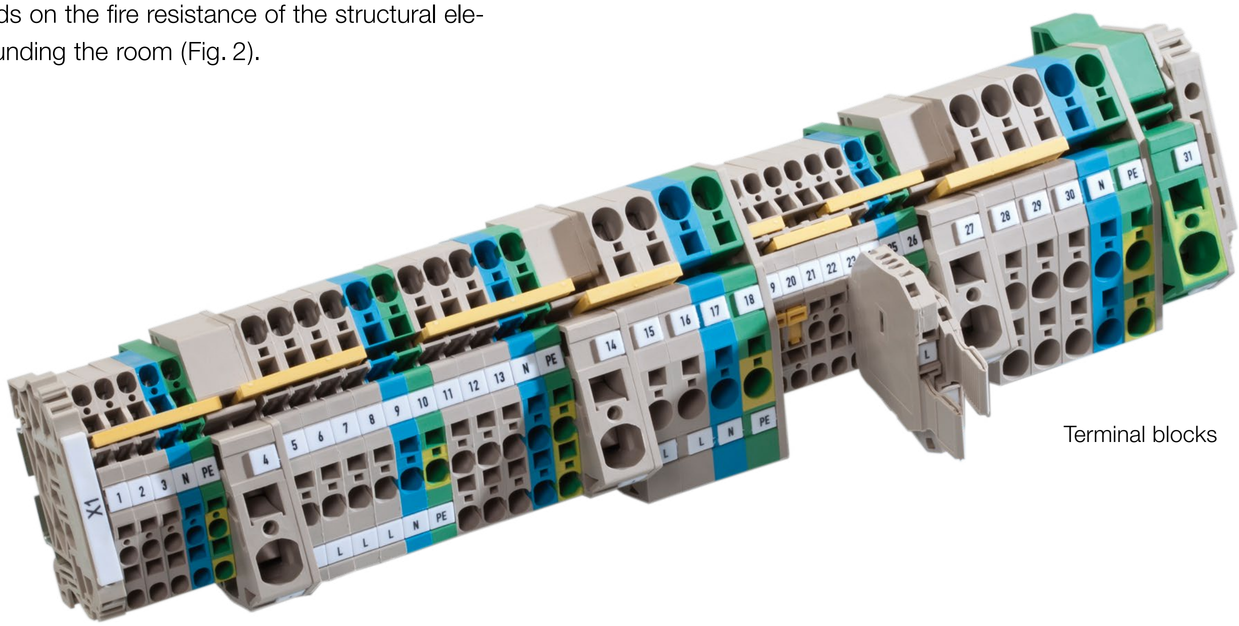


Fig. 2: Phases of the fire development in rooms according to Becker[3]



Terminal blocks

Parameters for describing the fire behavior

A fundamental presentation on the topic of the fire behavior of plastics can be found, for example, in Troitzsch[4]. The characteristic parameters for the fire behavior are:

- ignitability
- contribution to flame spread
- heat release

Side effects of fire are:

- flaming drips/falling material
- smoke generation (optical density and toxicity)
- toxicity of fire residues
- corrosiveness of combustion gases and fire residues

Fire tests are necessary in order to evaluate and rate the fire behavior. These tests should be representative and should closely reflect the situation of the fire hazard. Such tests are often conducted with test specimens having defined dimensions and under reproducible initial and boundary conditions. The objective of such tests is to ascertain comparable product-specific characteristic values.

However, since the fire behavior is not based only on the actual material properties, tests also have to be carried out on complete structures or components under conditions that are relevant for actual practice.

Ignitability and flame spread

The ignition initiates a combustion process. Ignition presupposes heating and decomposition of the burning materials in the area of action of the source of ignition. Thermoplastics soften when exposed to heat (glass transition, crystallite melt) and, as the temperature continues to rise, turn into a melt that gives rise to the flammable decomposition products. Once these products mix with the oxygen present in the air, the ignition can occur as self-ignition or external ignition at concentrations within the ignition limits and in the presence of sufficiently high energy.

In contrast to flammable liquids, when it comes to engineering plastics, like with all other flammable solid materials, it is not possible to indicate a flash point. Testing according to **DIN 54836**[5] yields ignition temperatures under exposure to flames of about 350 °C to 400 °C [662 °F to 752 °F]. Without exposure to flames, the thermal decomposition products only ignite at temperatures that are higher by about 50 °C to 100 °C [90 °F to 180 °F].

Combustion is an exothermal process. Part of the energy being released in the combustion zone is consumed to generate heat and to form flammable decomposition products. This process is called thermal feedback from the combustion zone to the heating zone. The ratio of the available amount of energy to the amount of energy needed to generate heat and to form flammable decomposition products determines the extent of flame spread on the surface of the flammable material. Therefore, flame spread can be considered to be a sequence of ignition processes.

Aside from the chemical make-up of the flammable material and its physical properties, for example, the viscosity of the melt, the course and scope of these processes are also influenced by additives such as stabilizers, colorants, lubricants. Insofar as a given plastic is not sufficiently inherently flame retardant, which is the case, for instance, with Ultrason®, the fire behavior can be improved by the addition of flame retardants, thus considerably reducing the contribution to the spread of the fire. Ignition can nevertheless occur here in the case of high ignition energies that are active for a prolonged period of time.

However, the burning is usually restricted to the direct range of action of the ignition source. Here, too, the rate of spread of the flames is much lower than for plastics without a fire-retardant finish. As soon as contact with the source of ignition is interrupted, the flames usually self-extinguish, especially in the early stages of a fire. Inherently flame retardant plastics and those with a fire-safety finish often attain the best possible ratings for flammable materials.

Material	Hu (kJ/kg)
Polyoxymethylene (POM)	17,000
Polyethersulfone (PESU)	17,000
Polyvinyl chloride (PVC)	20,000
Polymethyl methacrylate (PMMA)	26,000
Polybutylene terephthalate (PBT)	31,000
Polyamide (PA)	32,000
Polysulfone (PSU)	36,000
Styrene Copolymers (ASA, ABS, SAN)	37,000
Polystyrene (PS)	42,000
Polyolefins (PP and PE)	46,000

Tab. 1: Net calorific values of thermoplastics

Side effects of fire

For purposes of describing the fire development, it is important to know the heat release. The heat release is dependent on the combustion rate of the burning material under the present fire conditions, that is to say, the fire scenario. During a fire, the maximum heat quantity that can be released is the one corresponding to the heat of combustion. The heat of combustion is the released amount of heat released under standardized conditions – with the complete combustion of a material – minus the heat of evaporation of the water that is formed. Since the combustibility or the burning behavior is dependent on many influencing variables, the value of the net calorific value of a material cannot be regarded as a measure of its combustibility in the conventional sense. Table 1 is a compilation of net calorific values according to **DIN 51 900-1**[6] of commonly employed thermoplastics.

Smoke generation

Every fire generates gases as well as solid and/or liquid decomposition and secondary products of varying compositions. The liquid products are primarily water, while the solid products are soot. The term smoke is used when the combustion gases contain solid and/or liquid particles. This gives rise to various risks: smoke can reduce visibility as well as have a toxic and corrosive effect.

Smoke density

The optical density of the smoke determines the visibility conditions, thus affecting the possibilities of escape in case of a fire. In order to measure the smoke density, the principle of light extinction is normally employed: the weakening of a light beam of a known intensity caused by the smoke constitutes a measure of its optical density. Static (cumulative) as well as dynamic methods are employed for smoke measurement. The various test methods also differ in terms of the type of decomposition and the volume of oxygen available. Therefore, the values ascertained using different test methods cannot be compared to each other.

Toxicity

Combustion gases and fire residues stemming from plastics – like natural substances – always entail a toxic potential. In many cases, certain measures can prevent persons from being injured as a result of inhaling combustion gases. These measures include, in particular, restricting the ignitability and flame spread, the creation of escape routes and smoke and heat exhaust systems as well as fire detection and fire-fighting. If escape possibilities are limited or nonexistent (for example, in trains as they pass through tunnels, in airplanes, in ships), the composition of the combustion gases is often considered to be a safety-relevant aspect.

It is not only the materials involved that determine the toxicity of the combustion gases. The fire scenario (e.g. temperature, availability of oxygen) likewise has a major influence.

The essential components of all combustion gases are carbon dioxide, water and carbon monoxide resulting from incomplete combustion. The concentration ratios are influenced by the fire conditions. The content of carbon monoxide often determines the acute inhalation toxicity of the combustion gases. Carbon monoxide is almost always formed in sufficient amounts and quickly enough – in comparison to other components of the combustion gas – to be the first to exceed the lethal limit value. In individual cases, however, other combustion gas components can also pose a risk. A wide array of other substances can be generated as by-products and can have a sub-lethal effect.

For estimating the toxic potential, the concentration of relevant components in the combustion gas is compared to a known limit concentration. The IDLH (Immediately Dangerous to Life and Health) values often serve as the basis. It is assumed that escape is possible within 30 minutes if the IDLH values are not exceeded.

In order to make prognoses, Haber's rule is normally used: "If the product of the concentration and time remains the same, then the effect is the same." Consequently, the effective exposure dose for each gas component is defined as the product of the IDLH value (concentration) and the basic time of 30 minutes (Table 2).

The exposure dose can be calculated as the product of concentration and test time on the basis of the combustion gas concentrations measured during the course of the fire tests. The size of the specimen, the volume of the test chamber and the geometrical circumstances in the intended final application are all taken into consideration using a scale factor.

The so-called fractional effective exposure dose (FED) is then determined as follows:

$$FED = \frac{\text{existing exposure dose}}{\text{effective exposure dose}} = \int \frac{c(t)}{Ct_{eff}} dt$$

In other words, the measured exposure dose is compared to the effective exposure dose for the appertaining gas component. If the FED is less than 1, it can be assumed that survival or the ability to escape is ensured within the time under consideration.

For an approximate estimation of the total risk from all of the combustion gas components, a cumulative effect of the components found in the fire test is assumed. The total of the FED values for each component thus yields an FED_{total}.

Corrosiveness

Combustion gases of many organic substances have a corrosive effect, and combustion gases stemming from natural substances are no exception to this. For example, the combustion gases from wood contain acetic acid.

As a rule, combustion gases released by engineering plastics do not exhibit corrosiveness or have an irritating effect on the skin and respiratory tract that goes beyond the normal scope. If they have a fire-retardant finish containing halogen, then the corrosiveness and irritant effect can be stronger.

Gas component	IDLH-Value [mg/m³]
CO_2	72,000
CO	1,380
HF	25
HCl	75
HBr	99
HCN	55
NO_2	38
SO_2	262

Tab. 2: **IDLH** values from **NIOSH**[7]

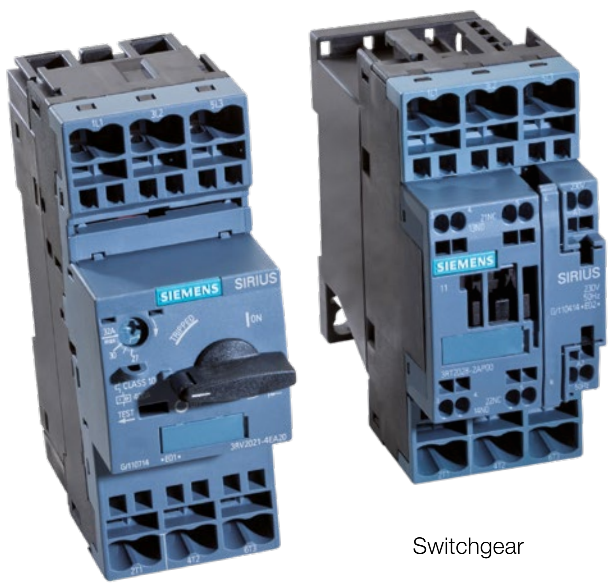
Measures after fire incidents

Fire water
Thermoplastics, like many other materials, are water-insoluble and are not considered to be hazardous to water. Consequently, there are no statutory stipulations requiring that the extinguishing water has to be contained. For reasons having to do with preventive water and soil protection, even when substances are stored that are not hazardous to water, it can still be advisable to take precautions to contain the accumulated extinguishing water, so that it cannot get into open bodies of water, groundwater or the soil.

Generally speaking, the competent authorities do not object to the discharging of extinguishing water from fires involving plastics into sewage-treatment plants. In this context, however, it should be kept in mind that plastics are often involved in the fire along with other materials, for example, the contents of containers. These might be hazardous to water. Moreover, in cases of fire, the fire department often employs special extinguishing agents, for instance, foams, some of which are classified as hazardous to water. In such cases, special precautions are required and there is a need to consult with the competent authorities.

Ecotoxicity studies carried out at the University of Wuppertal, Germany on extinguishing water from various sources have revealed that extinguishing water used in fires involving plastics does not entail a higher hazard potential than extinguishing water from fires where no plastics are involved (Pohl et al.[8]).

Fire residues
Fire residues have to be collected and disposed of in accordance with the statutory regulations applicable to the waste disposal, and in consultation with the competent authorities.



Switchgear

Applications and testing

Technical fire-protection requirements are safety requirements. They are always oriented towards the specific conditions of use, hazard potentials and associated safety objectives. Depending on the area of application, these requirements can vary quite widely.

The primary safety objective in many technical areas of application consists of preventing materials from catching fire due to possible sources of ignition as available, for example, to a smoker or an arsonist. Sources of ignition stemming from technical defects should also be taken into account. Thus, low ignitability of the flammable material is an essential fire-safety requirement. Should ignition occur nevertheless, then the contribution to the flame spread as well as to the generation of heat and smoke should not exceed tolerable limit values.

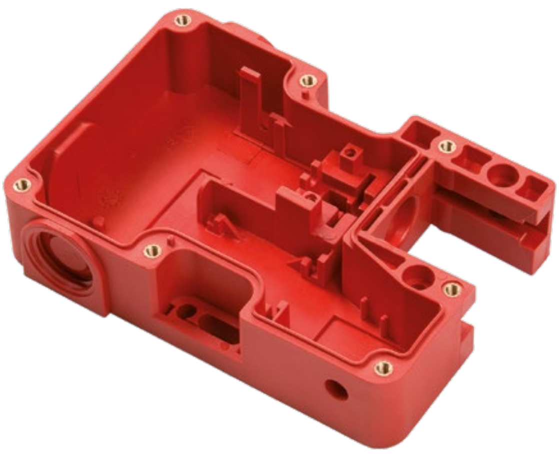
Therefore, whether a material is suitable for a given application or not can be ascertained on the basis of its fire behavior and the technical fire-safety requirements that are made in a given application case and that are stipulated in national and international standards or specifications.

Electrotechnical applications

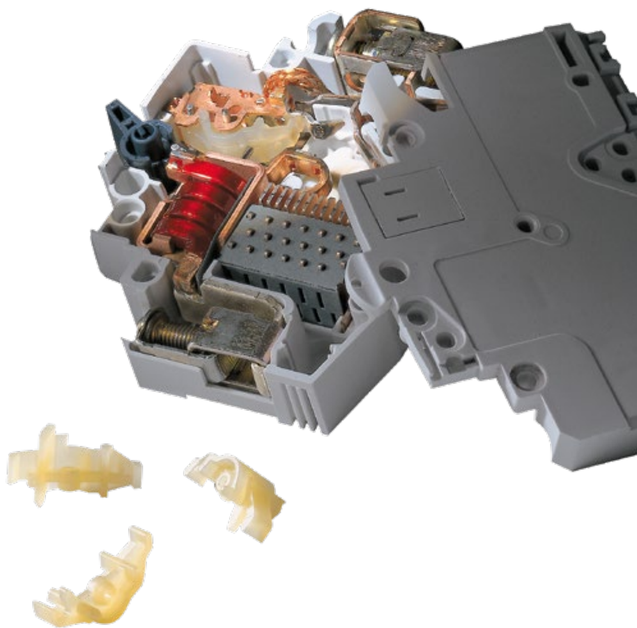
Overload, improper utilization as well as manufacturing and assembly errors such as defective soldered points or loose connections all constitute crucial fire hazards in electrotechnical products. Therefore, the objective from the standpoint of technical fire-safety in the eventuality of a malfunction is to prevent the ignition of the component and the spread of the fire to the immediate surroundings, for instance, the furnishings or the building. In certain cases, the additional requirement exists that the housing must not catch fire if exposed to an external source of ignition.

The technical fire-safety requirements are described in special safety regulations for electrically operated devices and installations. The measures required there are meant to ensure that the safety objective is achieved.

This also includes measures of a structural nature such as the limitation of the temperatures in case of malfunction or the use of materials that have a low level of ignitability and flame spread.



Safety switch housing



Ratchets for circuit breakers

As a result of the globalization of the electrotechnical industry in recent years, the regulatory works issued by the International Electrotechnical Commission (**IEC**) and the American Underwriters Laboratories (**UL**) have acquired special significance the world over. These regulatory works have evolved from national safety regulations such as those of the German Association for Electrical, Electronic and Information Technologies (**VDE**). This is also the source of many European standards (**EN Standards**) which have the status of national standards in the countries belonging to the **CENELEC** (Comité Européen de Normalisation Electrotechnique – European Committee for Electrotechnical Standardization). All of the countries of the European Community and Switzerland are members of CENELEC.

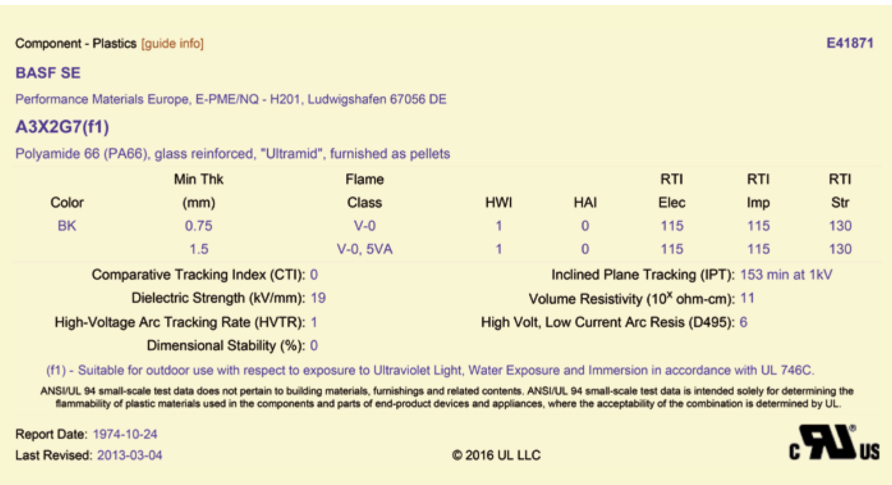
In accordance with the **WEEE Directive**[9] (Waste Electrical and Electronic Equipment), manufacturers of new electrical and electronic equipment in Europe are obliged to take back and recover old electrical and electronic devices. Plastics containing brominated flame retardants have to be segregated, which can entail substantial additional costs. The take-back and dismantling obligation has been in force in Germany and Denmark since April 2006. In Austria, Belgium and Ireland, this obligation has existed for quite some time while in France, Spain, Italy and Great Britain, it will take effect at a later point in time.

The WEEE Directive is complemented by **RoHS**[10] (Restriction of the use of certain hazardous substances in electrical and electronic equipment), which prohibits the use of certain environmentally hazardous substances. These include a number of brominated flame retardants. Such substances are not employed in the engineering plastics made by BASF.

Materials testing

A prerequisite for the use of plastics in electrotechnical applications is often that they have to comply with technical fire-safety standards. The pertinent tests on the materials already have to be conducted during their development and pre-selection, for purposes of approval, and during quality control. The test standards specify the type of the source of ignition and their effect on the test specimens as well as the test set-up and the dimensions of the test specimens for purposes of evaluating the ignitability and flame spread.

The **UL 94**[11] regulation of the Underwriters Laboratories is particularly important. Its contents have incorporated into **DIN IEC 60695-11-10**[12] and **-20**[13] as well as into the Canadian **CSA C22.2**[14]: the ignition sources employed are test flames with an output of 50 watts or 500 watts to which the test specimens are briefly exposed twice. In this process, the burning time and the dripping of burning particles are evaluated by means of a cotton indicator placed under the test specimen.



Component - Plastics [guide info] E41871

BASF SE

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

A3X2G7(f1)

Polyamide 66 (PA66), glass reinforced, "Ultramid", furnished as pellets

Color	Min Thk (mm)	Flame Class	HWI	HAI	RTI Elec	RTI Imp	RTI Str
BK	0.75	V-0	1	0	115	115	130
	1.5	V-0, 5VA	1	0	115	115	130

Comparative Tracking Index (CTI): 0
Inclined Plane Tracking (IPT): 153 min at 1kV
Dielectric Strength (kV/mm): 19
Volume Resistivity (10^x ohm-cm): 11
High-Voltage Arc Tracking Rate (HVTR): 1
High Volt, Low Current Arc Resis (D495): 6
Dimensional Stability (%): 0

(f1) - Suitable for outdoor use with respect to exposure to Ultraviolet Light, Water Exposure and Immersion in accordance with UL 746C.

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: 1974-10-24
Last Revised: 2013-03-04
© 2016 UL LLC
c US

Fig. 3: UL Yellow Card for Ultramid® A3XZG7

Fig. 4: Vertical burning test according to **UL 94**

The classification for the specimen in the tested thickness is made in five stages, namely, 5V, V-0, V-1, V-2 (vertical burning test) and HB (horizontal burning test) (Fig. 4-6, Table 3).

If self-colored products are to be manufactured, the approval must be given for the color batch in combination with the base material. For its products, BASF offers solutions together with several batch suppliers.

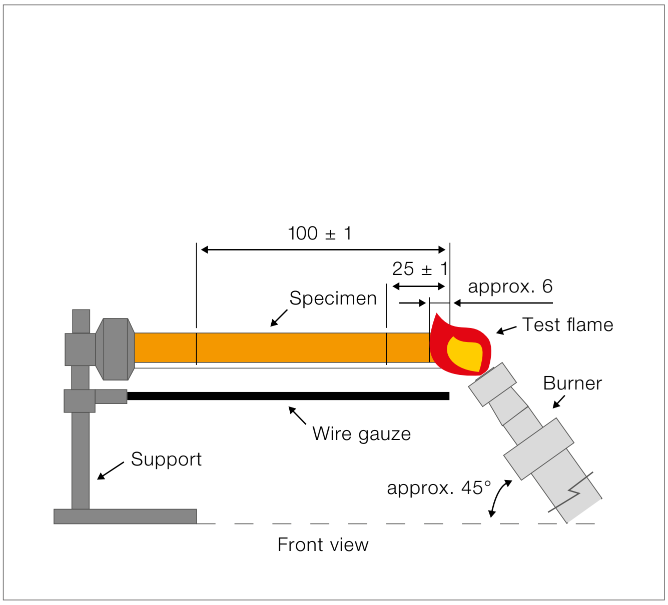


Fig. 5: **UL 94 HB** (or **DIN IEC 60695-11-10**)

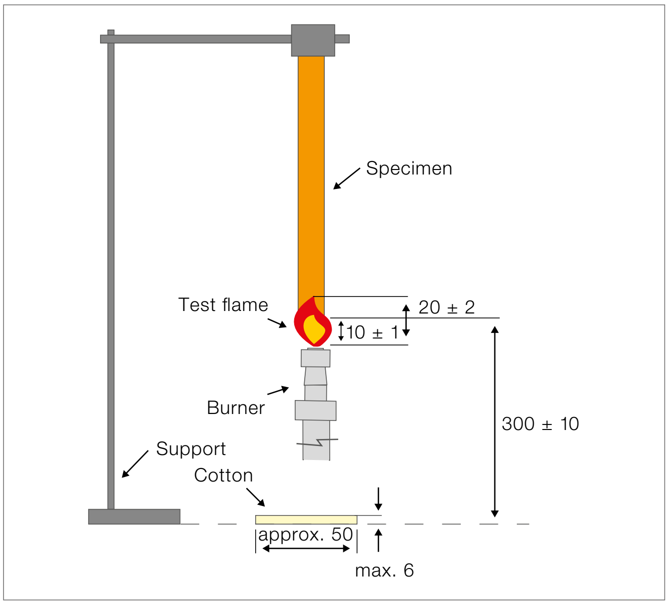


Fig. 6: **UL 94 V** (or **DIN IEC 60695-11-10**)

Horizontal Burning Test (UL 94 HB), flame: 50 W

Specimen thickness	Burning rate	Class	
Flame extinguishes before 100-mm mark	–	HB	
3-13 mm	≤ 40 mm/min	HB	
< 3 mm	≤ 75 mm/min	HB	

Vertical Burning test (UL 94 V), flame: 50 W

	V-0	V-1	V-2
Afterflame time for each Individual flaming	≤ 10 s	≤ 30 s	≤ 30 s
Total afterflame time for any condition set (10 flamings)	≤ 50 s	≤ 250 s	≤ 250 s
Afterflame plus afterglow time for each Individual specimen after 2nd flaming	≤ 30 s	≤ 60 s	≤ 60 s
Afterflame or afterglow of any specimen up to the holding clamp	no	no	no
Cotton indicator ignited by flaming drops	no	no	yes

Vertical Burning test (UL 94 5V), flame: 500 W; only materials that fulfill at least V-1

	5VA	5VB	
Afterflame plus afterglow time after 5th flaming, flame application for each specimen	≤ 60 s	≤ 60 s	
Cotton indicator ignited by flaming drops	no	no	
Complete Burning	no	no	
Burn-through (hole) of any plaque specimen	no	yes	

Tab. 3: Test criteria according to **UL 94**

The **UL 94 5V** test is conducted using a 125 mm (500 W) test flame on materials that have already been rated as V-1 or better according to UL 94. First, five flame treatments are carried out on bars, each for five seconds with a five second pause in between. If this first test step is passed successfully, plaque test specimens are tested in a second step using the same flame treatment (Fig. 7). If holes are formed on the plaques, the test is passed with a 5VB classification; if no holes are formed, the material is given a 5VA classification.

In the so-called Hot Wire Ignition Test (**HWI**) according to **ASTM D 3874**[16], an electrically heated resistance wire is wound around a horizontally arranged bar specimen. This simulates an ignition source resulting from overheating of the wires, especially in coils or transformers. The time when the specimen ignites (0 to 120 seconds) serves as the evaluation criterion for the classification into the ignitability categories PLC 0 to 5 (performance level categories) according to **UL 746 A, Section 31**[17] (Fig. 8).

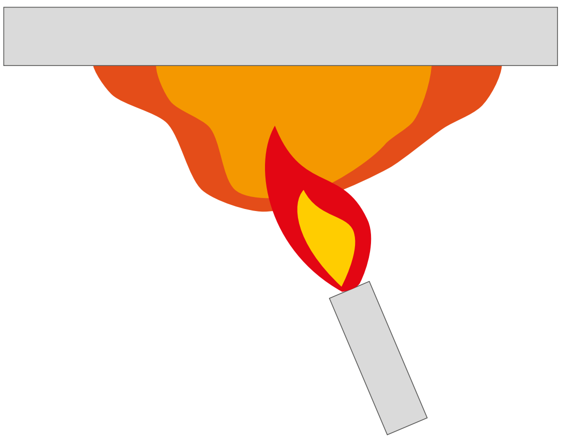


Fig. 7: **UL 94 5V** (or **DIN IEC 60695-11-20**), application of a 125 mm (500 W) test flame to plaques 150 · 150 mm²

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

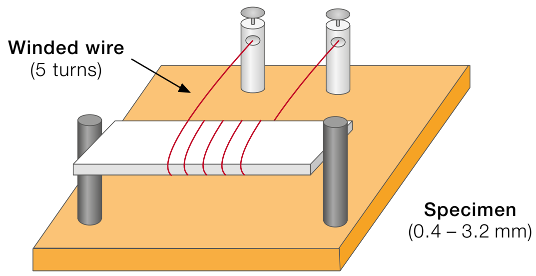
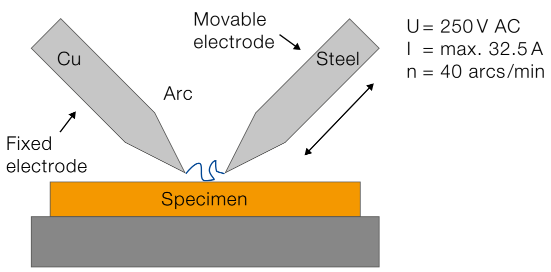


Fig. 8: Hot Wire Ignition Test (HWI) according to **ASTM D 3874**[16]



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

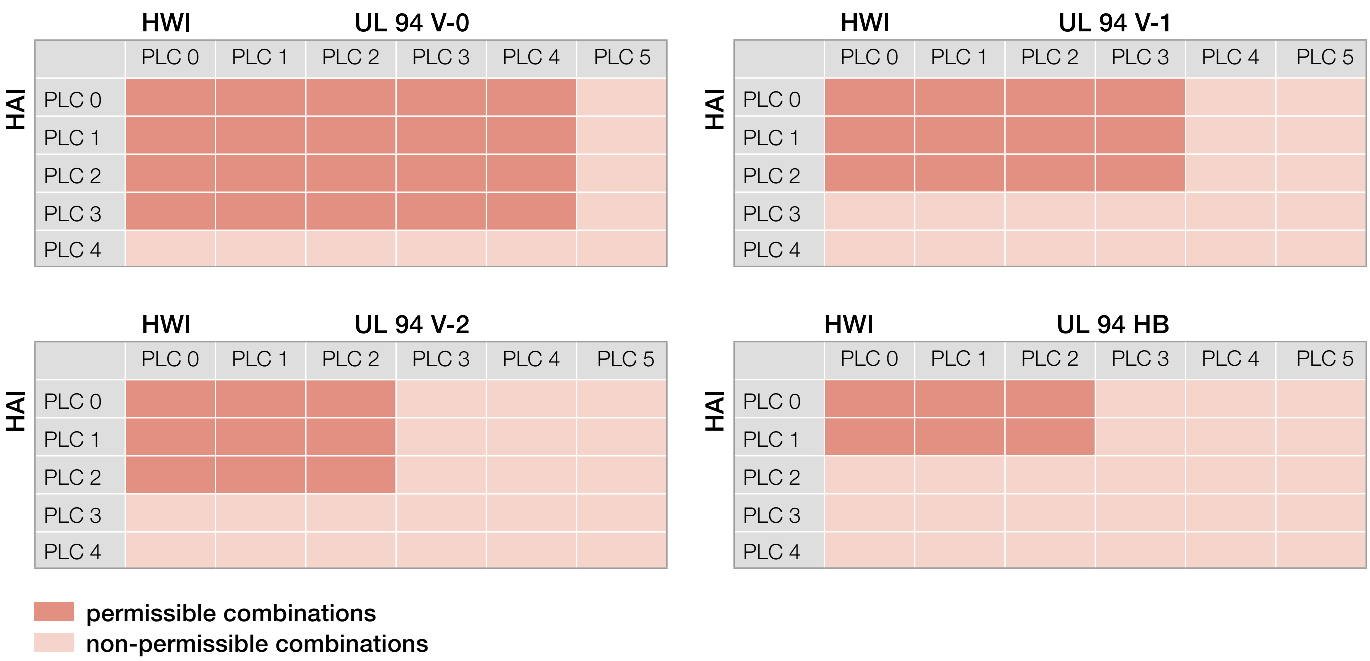
Fig. 9: High Current Arc Ignition Test (HAI) according to **UL 746 A, Section 32**[17]

In the so-called High Current Arc Ignition Test (HAI) according to **UL 746 A, Section 32**[17], a test specimen is exposed to regularly re-curring light arcs between two electrodes. With HAI, the number of light arcs up to ignition in PLC 0 to 4 is assessed (Fig. 9).

Within the Underwriters Laboratories (UL) standards, a plastic used as an insulating material in electrical applications must pass a combination of various flammability and ignition tests (**UL 746 C**). The specific requirements or level to be achieved in the relevant type tests are based both on the assessment of the existing appliance construction and on the application of the requirements (Table 4). The general rule is that the lower the flame retardance behavior of a plastic, the better its ignition performance must be.

The tendency towards tracking also depends on the properties of the material. This is characterized by the **C**omparative **T**racking **I**ndex (CTI) which gives a relative rating of polymers (Table 5).

Example: For UL 94 V-0, the plastic must have an additional HWI above PLC 4 and an HAI above PLC 3



Tab. 4: Demands on plastics for insulation purposes in E&E applications (**acc. to UL 746 C**)

Material group	U_{test}/V	CTI failure criteria:
I	$600 \le$ CTI	▪ Failure current I_F ≥ 0.5 A current for ≥ 2 sec ▪ Flame formation of ≥ 2 sec
II	$400 \le$ CTI < 600	
IIIa	$175 \le$ CTI < 400	
IIIb	$100 \le$ CTI < 175	

Tab. 5: Material groups acc. **DIN EN 60664-1**

Tracking can be caused by contamination of the surface. The CTI test according to standard **IEC/DIN EN 60112** tries to simulate this by exposing the surface to a conductive test solution (Figs. 10 and 11).

The sample is thermally decomposed by the light arcs, then traces of carbon black and ultimately tracks can be seen. This significantly reduces the insulating ability between two live contacts. In the CTI test, a test specimen is sprinkled successively between two live electrodes with 50 drops of an electrolytic solution. The CTI is the numerical value of the highest voltage at which no failure occurred on five samples after 50 applications of drops respectively.

The **DIN IEC 60695-2-10**[15] to **-13** series of standards describes ignition tests employing a glow-wire. Here, overheated or incandescent metal parts are simulated. The wire loop heated up to the prescribed test temperature is pressed against the molded part that is being examined. It is then ascertained whether the test specimen ignites, whether the flames spread and whether flaming drips occur in a manner that promotes combustion. The glow-wire test can be carried out on standardized test plaques as well as on finished components (Fig. 12).

Parts testing

Not only the properties of the material but also the geometrical shape determine the fire behavior of the final product. This is why it is often necessary to also carry out tests on the finished parts.

This is taken into consideration in the completely revised standard on the safety of electric household appliances, **IEC/DIN EN 60335-1**[18]. Section 30 provides a general description of the requirements made in terms of the heat and fire resistance (Fig. 13).

The highest requirements apply to household appliances which operate unattended and through which high currents flow (bigger than 0.2 A).These include switches and connections in washing machines and dishwashers, refrigerators and ovens as well as electric motors in central vacuum systems or exhaust hoods. Plastics used in these devices fundamentally have to pass an ignitability test for the material (GWFI) according to **DIN IEC 60695-2-12**[19] at 850 °C [1562 °F] (extinction of the flame within the testing and observation time of 60 seconds). In addition, requirements call for a glow-wire test on standardized test plaques according to **DIN IEC 60695-2-13**[20] (GWIT at 775 °C [1427 °F], maximum flame duration of 5 seconds). If such a value is not attained, then as an alternative, the finished component can undergo a test according to **DIN IEC 60695-2-11**[21] (GWEPT, Glow Wire End Product Test, at 750 °C [1382 °F], but by a stricter regulation of the maximum flame duration of 2 seconds according to **IEC/DIN EN 60335-1**[18]) or one of three other possible tests on the

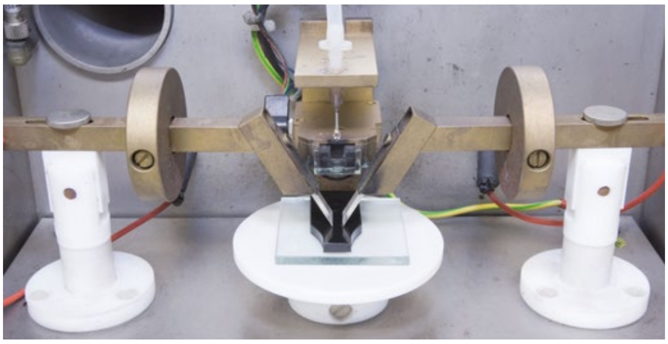


Fig. 11: CTI, actual test set-up

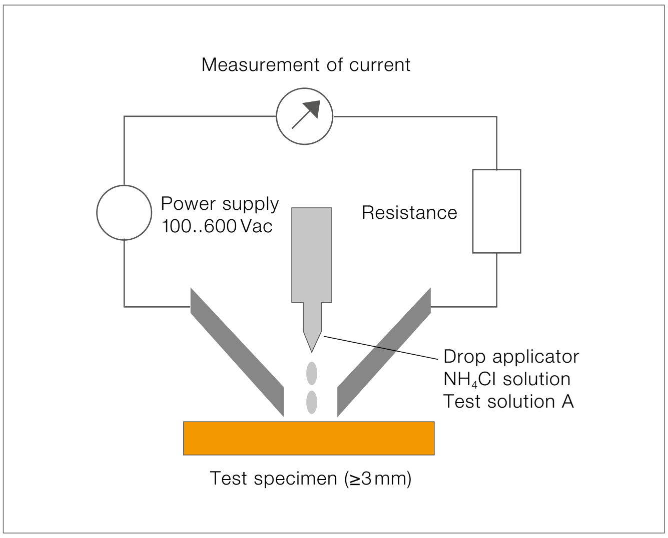


Fig. 10: CTI, measuring principle

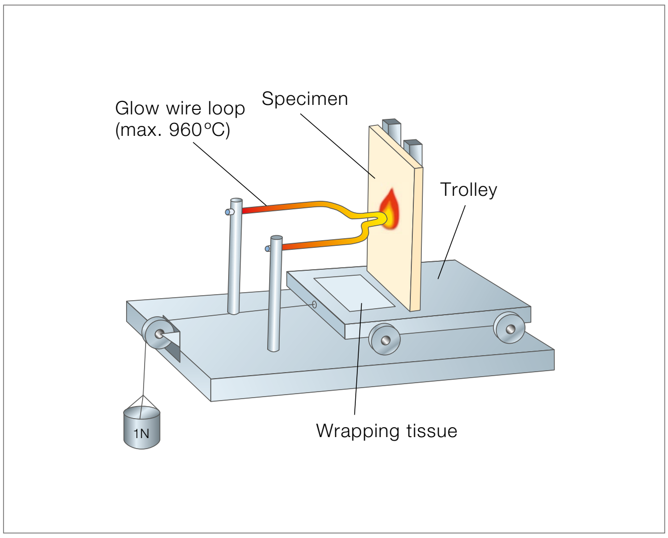


Fig. 12: Glow-wire test according to **DIN IEC 60695-2-10**[15]

surrounding components. Figure 13 shows the maximum necessary requirements.

Only a few of the plastics currently found on the market can comply with the stricter standard, which started being phased in as of the autumn of 2005, depending on the type of appliance. In order to reduce the work for appliance manufacturers, a certification system for plastic components involving the active participation of BASF was introduced at the German Association for Electrical, Electronic and Information Technologies (VDE). In this manner, a preselection of the material gives appliance manufacturers the certainty they need for their planning and also saves time and money involved in testing many component geometries during the testing of the final device. The certification and annual inspection encompasses the material (GWFI19 and GWIT20 test) as well as the appertaining production facility. At the present time (August 2011), more than ten different halogen-free Ultramid® types in various color and thickness variants have already been certified and certification is anticipated for additional materials (Fig. 14).

Tests involving the effect of flames are also important. Ignition flames can affect an electrotechnical product from the inside as well as from the outside. Especially cables and lines can be exposed to the external effects of flames when a fire breaks out.

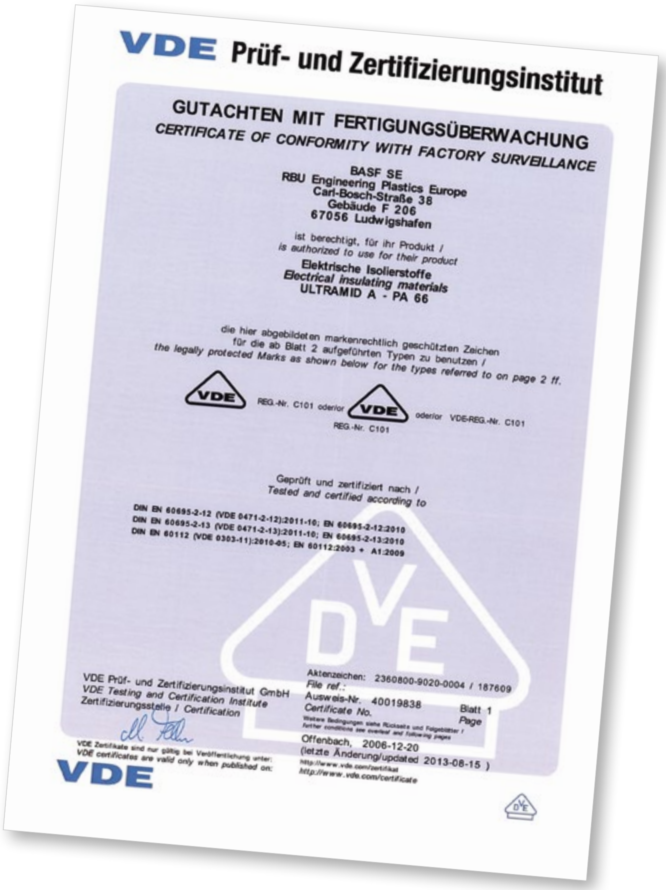


Fig. 14: VDE certificate for BASF's Engineering Plastics Europe Regional Business Unit

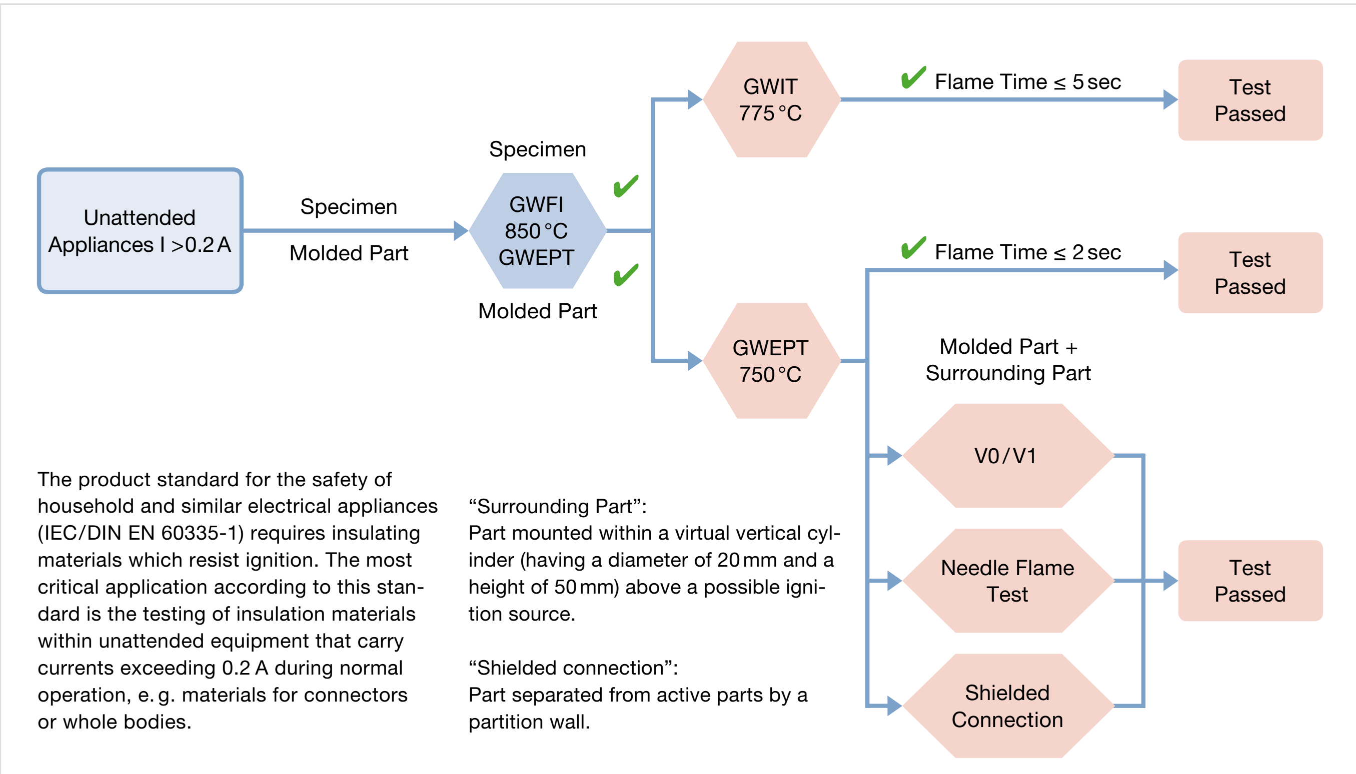


Fig. 13: Selection and sequence of tests for resistance to heat and fire according to **IEC/DIN EN 60335-1**, Section 30.2.3.

Several product standards require the needle-flame test according to **IEC/DIN EN 60695-11-5**[22] or **UL 746 C**[23]. Here, a 12 mm long test flame is held for a certain period of time (intensity levels) at the edges or surfaces of molded parts. The evaluation examines the afterflame time following exposure to the flame and checks whether a cotton indicator positioned underneath was ignited by dripping material (Fig. 15).

Safety requirements for the fire protection of audio/video equipment and for information and communication technology are defined in the standards **IEC/DIN EN 60065**[24] and **IEC/DIN EN 60950-1**[25]. Since 2014, the so-called Hazard Based Standard **IEC/DIN EN 62368-1**[26] has also been available in parallel. This will replace **IEC/DIN EN 60065**[24] and **IEC/DIN EN 60950-1**[25] in the medium term. There are regional differences, some of which are significant, in the specific requirements. For example, for what are known as fire protection housings, materials that conform to at least class V-1 according to **IEC/DIN EN 60695-11-10**[12] are required. Another persistent discussion, in Europe in particular, relates to the introduction of requirements for external ignition sources ("Candle Flame Ignition Test" according to **IEC/TS 62441**[27]).

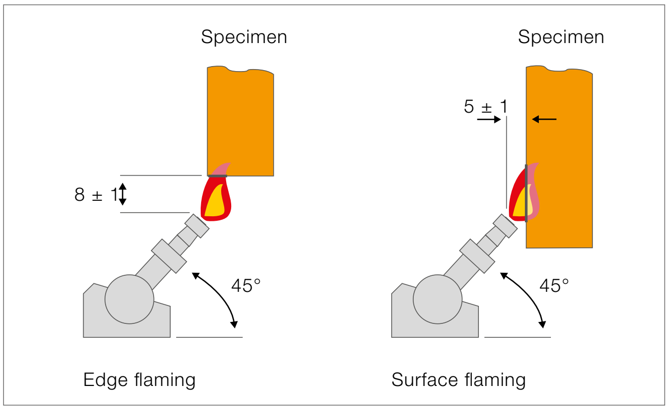


Fig. 15: needle-flame test **IEC/DIN EN 60695-11-5**

Fire-protected products in electrotechnical applications
BASF's engineering plastics with flame-retardant properties are employed, for example, for plugs and plug connectors, mountings and terminals, relays and low-voltage switching devices (for instance, protective motor switches and circuit breakers). The available BASF product portfolio can be found in the current BASF product literature.

Switchgear

Transportation

In modern mass transit and transportation engineering, plastics make a substantial contribution to the high level of performance of cars, trains, coaches and airplanes. Whereas the focus used to be primarily on economic considerations, nowadays there is great demand for plastics when it comes to meeting further requirements such as better road safety, reduction in weight, an attractive design, and greater comfort.

In modern mid-size cars, plastics already account for more than 200 kg and the weight fraction of plastics will continue to grow. In a volume-based comparison, which seems reasonable given the low density, the plastics content is already over 40 percent. Over 60 percent of all plastics are used in the interior, followed by the chassis, the exterior, powertrain, electrics and electronics (Fig. 16).

Motor vehicles

Investigations into the cause of vehicle fires have shown that a large proportion of these fires start in the engine compartment. One example of a major cause is combustible materials such as fuel or lubricants being ignited on hot surfaces. But fires can also be caused by electrical faults – associated with sparking or overheating. However, this hazard can be effectively prevented by choosing suitable materials and constructive measures.

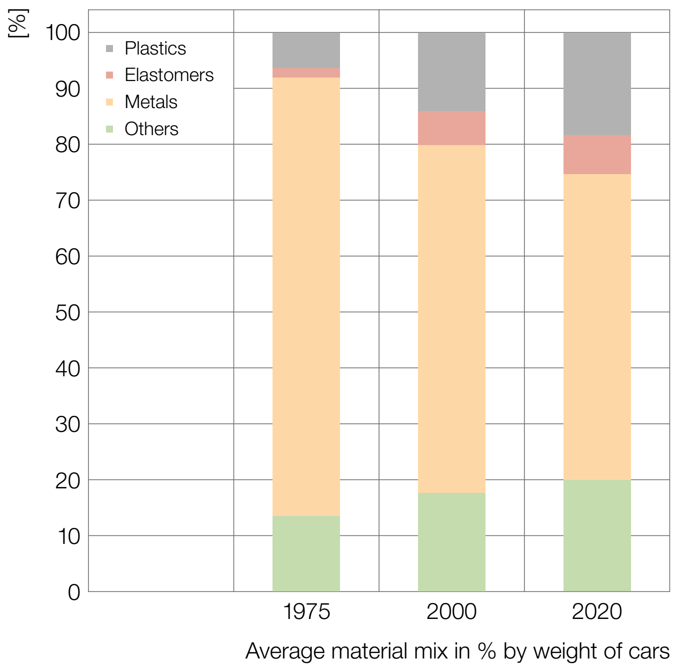


Fig. 16: Material mix in passenger cars from 1975 to 2020 (Source: A. T. Kearney)

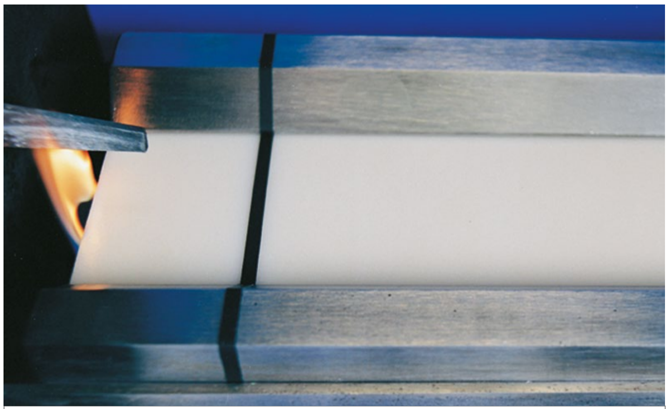
Transmission control

Materials that are used inside of vehicles must display a low risk of ignition and flame propagation speed. This is intended to ensure that there is a sufficient amount of time to stop a vehicle even at high speed and exit the vehicle in good time.

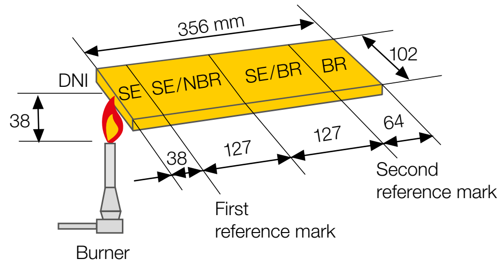
The test procedure, which has been introduced in the USA as the Federal Motor Vehicle Safety Standard (**FMVSS 302**[28]), has been adopted by many other standards (e.g. **DIN 75200**[29], **ISO 3795**[30]) and the delivery specifications of most car manufacturers around the world: After exposing the horizontally arranged test specimen to the flame (for 15 seconds) using a Bunsen burner, the propagation speed of the flames is determined. The highest permitted value is 4 inches/min or 102 mm/min (Fig. 17).

The measured propagation speed of the flames is dependent on the thickness of the test specimen. Most of BASF's engineering plastics meet the requirements at thicknesses of 1 millimeter. However, the rising number of electrical components with high power output is increasing the demand for flame-retardant thermoplastics. Details of suitable materials can be found in the current BASF literature.

BASF works with masterbatch producers such as BASF Color Solutions to develop self-coloring solutions which make it possible to produce colors economically at the customer's premises.



Fire testing according to FMVSS 302

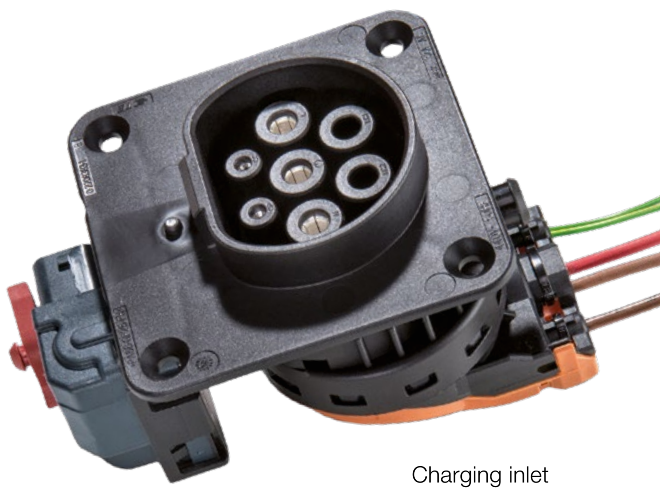


DNI	does not ignite
SE	self-extinguishing
SE/NBR	self-extinguishing/ no burn rate
SE/BR	self-extinguishing with burn rate
BR	burn rate

Test conditions:
- Thickness of test specimen as in application
- Horizontal specimen
- Flame application using a Bunsen burner (15 sec.)

Requirements: Maximum rate of flame spread: 102 mm/min

Fig. 17: Fire test for materials used in the interior of vehicles, according to **FMVSS 302**[28]



Charging inlet

Coaches

The EC Directive **95/28/EC**[31] specifies the requirements for motor vehicles with more than 22 passenger seats and a maximum weight of more than 5 tons (coaches). Accordingly, interior linings, light fittings, seats, ventilation pipes, insulation materials and floor coverings must be tested in accordance with Appendix IV (**FMVSS 302**[28]). The test is deemed to have been passed if the horizontal burning rate is not more than 100 mm/min or if the flame extinguishes before the second measuring mark is reached.

At an international level, **UN/ECE R 118**[32] also defines among other things the requirements concerning the burning behavior of materials used in the interior fittings and electric cables.

In Appendix V, a drip test based on **NF P 92-505**[33] (Epiradiateur test) is additionally requested for all parts situated in the roof, but with an irradiance of 30 kW/m^2. Substances that drip burning material in this test and cause the cotton indicator to ignite may not be used.

Rail vehicles

The most frequent causes of fires in rail vehicles are intentional arson or negligence and defects in the electrical systems. Rail vehicles in Europe have previously been governed by different national regulations, but these are increasingly being harmonized.

In order to make the terms of delivery uniform, the UIC (Union Internationale des Chemins de Fer), an alliance of European and Asian railroad administrative bodies, has drawn up technical fire-safety recommendations in its code **UIC 564-2**[34]. Parts of this, especially the testing of seats, have been adopted in many national sets of regulations.

In order to ensure so-called interoperability in trans-European high-speed transit, the European standards series **EN 45545** has been introduced. It contains seven sections in total and formulates measures and requirements for preventive fire protection in rail vehicles and the associated detection methods.

EN 45545-1[35] defines the different operation and design categories with the hazard levels to be derived from them (Table 6). **EN 45545-2**[36] defines the corresponding fire safety requirements for materials and components. These materials and components are grouped into component numbers according to their intended use (Table 7a). Each component group has one of the requirement sets R1 – R26 assigned to it (Table 7b). The requirements for non-listed components are mentioned in Table 8. Certain rules for grouping must be followed here if necessary.

Operation category	Design category			
	N Standard vehicles	**A** Vehicles for automatic drive mode*	**D** Double-deck vehicles	**S** Sleeping cars and couchettes
1	HL1	HL1	HL1	HL2
2	HL2	HL2	HL2	HL2
3	HL2	HL2	HL2	HL3
4	HL3	HL3	HL3	HL3

Tab. 6: **DIN EN 45545-1** Assignment of the hazard levels (HL)
*no staff trained to handle emergencies on board

Product No.	Name
IN	Located internally
EX	Located externally
F	Furnishing
E	Electrotechnical equipment
M	Mechanical equipment

Tab. 7a: Classification of components

Component No.	Name	Description	Requirement
EL6A	Supply line system and high-power components – internal	Insulators; current and voltage transformers; main switches; contactors	R22
EL6B	Supply line system and high-power components – external	Insulators; current and voltage transformers; main switches; contactors	R23
EL7A	Inductors and coils – internal	Inductors for filtering the supply line, windings for air-cooled transformers, including spacers and air baffles	R22
EL7B	Inductors and coils – external	Inductors for filtering the supply line, windings for air-cooled transformers, including spacers and air baffles and insulation for the drive motor winding	R23
EL10	Small electrotechnical components	Examples include low-power circuit breakers, excess power relays, contactors, contact relays, switches, control or signal switches, terminals, fuses	R26

Tab. 7b: **DIN EN 45545-2** Requirements for listed components (extract)

Exposed surface area	Location of use	Requirement set in Table 9
$> 0{,}20\,m^2$	internal	R1
$> 0{,}20\,m^2$	external	R7
$\leq 0{,}20\,m^2$	internal	R22
$\leq 0{,}20\,m^2$	external	R23

Tab. 8: **DIN EN 45545-2** Requirements for non-listed components according to the exposed surface area and the location of use in the vehicle

The material requirements are listed in sets of requirements. These include tests to determine the flame spread (**EN ISO 5658-2**[37]), the heat release rate using the cone calorimeter method (**ISO 5660-1**[38]), and smoke generation and toxicity in the smoke chamber (**EN ISO 5659-2**[39]). Examples are listed in Table 9.

In principle, **EN 45545** should be used from 2016; the previous national standards or tests in relation to fire protection in rail vehicles remain valid alongside this standard for a transitional period, in some cases until 2017:

- British standards **BS 6853 EN**[40], GM/RT2130 issue 3
- French standards **NF F 16-101**[41] and **NF F 16-102**[42]
- German standard **DIN 5510-2**[43] including toxicity measurements
- Italian standards **UNI CEI 11170-1**[44] and **UNI CEI 11170-3**[45]
- Polish standards **PN-K-02511**[46] and **PN-K-02502**[47]
- Spanish standard **DT-PCI/5A**[48]

Requirement set	Reference to test procedures	Parameter and unit	Maximum or minimum	HL1	HL2	HL3
R22 (IN16; EL2; EL6A; EL7A; M2)	T01 EN ISO 4589-2, OI	Oxygen index (OI) %	Minimum	28	28	32
	T10.03 EN ISO 5659-2, 25 kW/m^{-2}	D_S max. dimensionless	Maximum	600	300	150
	T12 NF X 70-100-1, 600 °C und NF X 70-100-2, 600 °C	CIT $_{NLP}$ dimensionless	Maximum	1.2	0.9	0.75
R23 (EX12; EL2; EL5 EL6B; EL7B; M3)	T01 EN ISO 4589-2, OI	Oxygen index (OI) %	Minimum	28	28	32
	T10.03 EN ISO 5659-2, 25 kW/m^{-2}	D_S max. dimensionless	Maximum	–	600	300
	T12 NF X 70-100-1, 600 °C und NF X 70-100-2, 600 °C	CIT $_{NLP}$ dimensionless	Maximum	–	1.8	1.5
R24	T01 EN ISO 4589-2, OI	Oxygen index (OI) %	Minimum	28	28	32
R25 (EL9)	T16 EN 60695-2-11	Glow wire temperature °C	Minimum	850	850	850
R26 (EL10)	T17 EN 60695-11-10	Vertical small burner test	Minimum	V0	V0	V0

Tab. 9: **DIN EN 45545-2** Material requirements (extract)

Electrotechnical products

The fire behavior requirements of electrotechnical products are related to those of the VDE set of rules. If there is any doubt, it must be established whether electrotechnical products which bear a VDE mark also meet the requirements of **EN 45545** or whether any additional tests or certificates from European testing and certifying bodies are required.

Fire-retardant products for rail vehicles

BASF's engineering plastics are also used in particular for electrical applications in rail vehicles. Material recommendations and details of attained hazard levels and requirement sets can be found in the current BASF product literature.

Aviation

Commercial aircraft throughout the world have to meet the technical fire-safety requirements of the American Federal Aviation Regulations (**FAR 25.853**[49]). The terms of delivery of the aircraft manufacturers and airline companies contain some requirements that go beyond those of the FAR, particularly with regard to smoke generation and the toxicity of the combustion gases. The safety concept also encompasses a post-crash fire. Accordingly, provisions are made for the testing of aircraft seats and large-surface parts in the cabin area under very high heat exposure. Moreover, the walls of the cargo area should be configured in such a way that a fire originating in the cargo area with high heat release cannot spread to the rest of the aircraft.

For example, foams made of Ultrason® E are approved for use in aircraft. This material, with its exceptionally high limiting oxygen index of 38 (according to **ASTM D 2863**[50]), is noted for the fact that it already meets the requirements for commercial aircraft with regard to combustibility and heat release, even without the addition of flame retardants, and so is intrinsically flame-retardant.

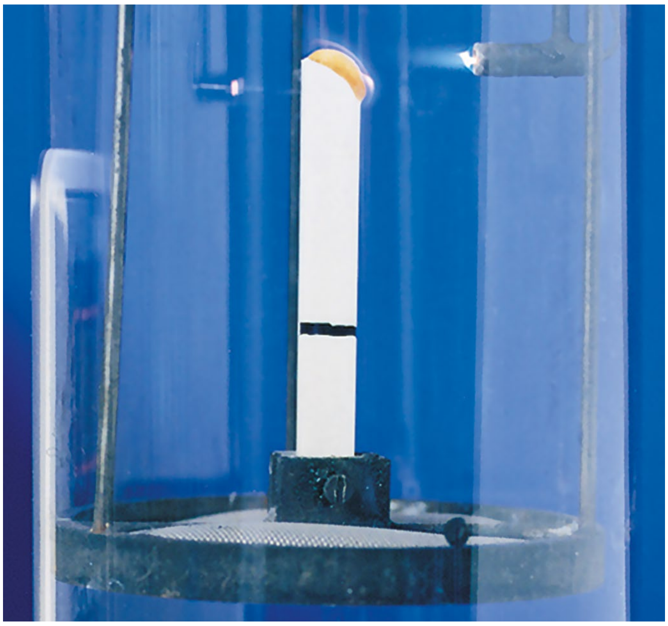


Fig. 18: Oxygen index (LOI) test according to **ASTM D 2863**[50]

BASF Fire Technology Laboratory

Following a holistic approach, BASF supports its customers from the development of a product through to its registration. Customers can conduct fire testing on BASF products in our own fire technology laboratory. Our laboratory is certified according to **DIN EN ISO/IEC 17025** and thus guarantees a dependable and independent evaluation. About 35 test stands offer the possibility to perform fire and flammability tests according to almost 100 international norms in areas such as automotive, construction, consumer products, and railway. Special testing can be arranged upon request.

Certified by:
- Deutsche Akkreditierungsstelle GmbH
- Certifier – Railway Certification

For further information and offers, please contact:
BASF SE
Fire Technology
67056 Ludwigshafen, Germany
www.basf.com/plastics/fire-testing

Notes

Literature

[1] DIN EN ISO/IEC 17025 Allgemeine Anforderungen an die Kompetenz von Prüf- und Kalibrierlaboratorien

[2] Seekamp, H. Das Brandgeschehen und die Systematik der Prüfmethoden, Materialprüfung 5 (1963) 2, Seiten 45-49

[3] Becker, W. Brandgefahr und Prüfung des Brandverhaltens von Kunststoffen, Kunstst. Plast. (Solothurn, Schweiz) 22 (1975) 6, Seiten 19-25

[4] Troitzsch, J. Plastics Flammability Handbook – Principles, Regulations, Testing, and Approval, 3rd edition, München, Wien, Carl Hanser Verlag (2004)

[5] DIN 54836 Prüfung von brennbaren Werkstoffen; Bestimmung der Entzündungstemperatur

[6] DIN 51900-1 Bestimmung des Brennwertes mit dem Bomben-Kalorimeter und Berechnung des Heizwertes, Teil 1: Allgemeine Angaben, Grundgeräte, Grundverfahren

[7] NIOSH (National Institute for Occupational Safety and Health) pocket guide to chemical hazards

[8] Pohl, K. D. et al. Analytik kontaminierter Löschwässer, Wasser, Luft und Boden, 9 (1994), Seiten 38-43

[9] Richtlinie 2002/96/EG (Waste Electrical and Electronic Equipment WEEE) über Elektro- und Elektronik-Altgeräte

[10] Richtlinie 2002/95/EG (Restriction of the use of certain hazardous substances in electrical and electronic equipment RoHS) Richtlinie zur Beschränkung der Verwendung bestimmter gefährlicher Stoffe in Elektro- und Elektronikgeräten

[11] UL 94 Tests for flammability of plastic materials for parts in devices and appliances

[12] IEC/DIN EN 60695-11-10 Prüfungen zur Beurteilung der Brandgefahr, Teil 11-10: Prüfflammen – Prüfverfahren mit 50-W-Prüfflamme horizontal und vertikal

[13] IEC/DIN EN 60695-11-20 Prüfungen zur Beurteilung der Brandgefahr, Teil 11-20: Prüfflammen – Prüfverfahren mit einer 500-W-Prüfflamme

[14] CSA C 22.2, No. 0.17-92 Evaluation of Properties of Polymeric Materials – General Requirements; Part 4: Flame Test Procedure

[15] DIN IEC 60695-2-10 Prüfungen zur Beurteilung der Brandgefahr; Teil 2-10: Prüfungen mit dem Glühdraht, Glühdrahtprüfeinrichtungen und allgemeines Prüfverfahren

[16] ASTM D 3874-04 Test Method for Ignition of Materials by Hot Wire Sources

[17] UL 746 A, Polymeric Materials – Short Therm property Evaluations

[18] IEC/DIN EN 60335-1 Sicherheit elektrischer Geräte für den Hausgebrauch und ähnliche Zwecke – Teil 1: Allgemeine Anforderungen

[19] DIN IEC 60695-2-12 Prüfungen zur Beurteilung der Brandgefahr; Teil 2-12: Prüfung mit dem Glühdraht zur Entflammbarkeit von Werkstoffen (GWFI)

[20] DIN IEC 60695-2-13 Prüfungen zur Beurteilung der Brandgefahr; Teil 2-13: Prüfungen mit dem Glühdraht zur Entzündbarkeit von Werkstoffen (GWIT)

[21] DIN IEC 60695-2-11 Prüfungen zur Beurteilung der Brandgefahr; Teil 2-11: Prüfung mit dem Glühdraht zur Entflammbarkeit von Enderzeugnissen (GWEPT)

[22] IEC/DIN EN 60695-11-5 Prüfungen zur Beurteilung der Brandgefahr; Teil 11-5: Prüfflammen – Prüfverfahren mit der Nadelflamme

[23] UL 746 C Polymeric Materials, Use in Electrical Equipment Evaluations

[24] IEC/DIN EN 60065 Audio-, Video- und ähnliche elektronische Geräte; Sicherheitsanforderungen

[25] IEC/DIN EN 60950-1 Information technology equipment – Saftey – Part 1: General requirements

[26] IEC/DIN EN 62368-1 Audio/video, information and communication technology equipment – Part 1: Saftey requirements

[27] IEC/TS 62441 Safeguards against accidentally caused candle flame ignition for audio/video, communication and information technology equipment

[28] FMVSS 302 Flammability of interior materials – passenger cars, multipurpose passenger vehicles, trucks and buses, § 5 71.302 Standard No. 3 02, 4 9 CFR Ch.V, National Highway Traffic Safety Administration, DOT

[29] DIN 75200 Bestimmung des Brennverhaltens von Werkstoffen der Kraftfahrzeuginnenausstattung

[30] ISO 3795 Road vehicles and tractors and machinery for agriculture and forestry; Determination of burning behavior of interior materials

[31] Directive 95/28/EC Burning behaviour of materials used in the interior construction of certain categories of motor vehicle

[32] UN/ECE R 118 Regelung für Brennverhalten von Innenraummaterial

[33] NF P 92-505 Bâtiment – Essais de réaction au feu des matériaux; Essais applicables aux matériaux thermofu-sibles: Essai de goutte

[34] UIC 564-2 Vorschriften über Brandverhütung und Feuer-bekämpfung für die im internationalen Verkehr eingesetzten Schienenfahrzeuge, in denen Reisende befördert oder die der Reisezugwagenbauart zugeordnet werden

[35] EN 45545-1 Railway applications – Fire protection on railway vehicles – Part 1: General

[36] EN 45545-2 Railway applications – Fire protection on railway vehicles – Part 2: Requirements for fire behaviour of materials and components

[37] EN ISO 5658-2 Reaction to fire tests – Spread of flame – Part 2: Lateral spread on building and transport products in vertical configuration

[38] ISO 5660-1 Reaction-to-fire tests. Heat release, smoke production and mass loss rate. Heat release rate (cone calorimeter method) and smoke production rate (dynamic measurement)

[39] EN ISO 5659-2 Plastics – Smoke generation – Part 2: Determination of optical density by a single-chamber test

[40] BS 6853 EN Code of practice for fire precautions in the design and construction of passenger carrying trains

[41] NF F 16-101 Rolling stock. Fire behaviour. Materials choosing

[42] NF F 16-102 Railway rolling stock. Fire behaviour. Materials choosing, application for electric equipments

[43] DIN 5510-2 Preventive fire protection in railway vehicles – Part 2: Fire behaviour and fire side effects of materials and parts – Classification, requirements and test methods

[44] UNI CEI 11170-1 Protective rail vehicle – track vehicle guidance. General principles

[45] UNI CEI 11170-3 Fire testing to fire components – Guidelines for railway vehicle protection for tramways and with guided rail. Part 3: Assessment of fire behaviour of materials, acceptance limits

[46] PN-K-02511 Tabor kolejowy – Bezpieczeństwo przeciwpożarowe materiałów – Wymagania (Rolling stock – Fire safety, materials – Requirements)

[47] PN-K-02502 Tabor kolejowy – Podatność na zapalenie siedzeń wagonowych – Wymagania i badania (Rolling stock – Resistance against ignition of seating – Require-ments and tests)

[48] DT-PCI/5A Directriz técnica para reacción al fuego de los materiales de decoración e interiorismo de vehículos destinados al transporte de viajeros

[49] Federal Aviation Regulation (FAR) Airworthness Standards. US Department of Transportation, Federal Aviation Administration, §§ 25.851 ff: Fire Safety

[50] ASTM D 2863 Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-like Combustion of Plastics (Oxygen-Index)

Engineering plastics for the E&E industry – Literature:

- Engineering plastics for the E&E industry – Standards and ratings
- Engineering plastics for the E&E industry – Products, applications, typical values
- Engineering plastics for automotive electrics – Products, applications, typical values

Further information on Ultramid® can be found on the internet:

www.ultramid.basf.com

Please visit our websites:

www.plastics.basf.com

www.plastics.basf.de

Request of brochures:

plas.com@basf.com

If you have technical questions on the products, please contact the Ultra-Infopoint:

Ultra Infopoint

+49 621 60-78780

ultraplaste.infopoint@basf.com

PMEI 1902 BE