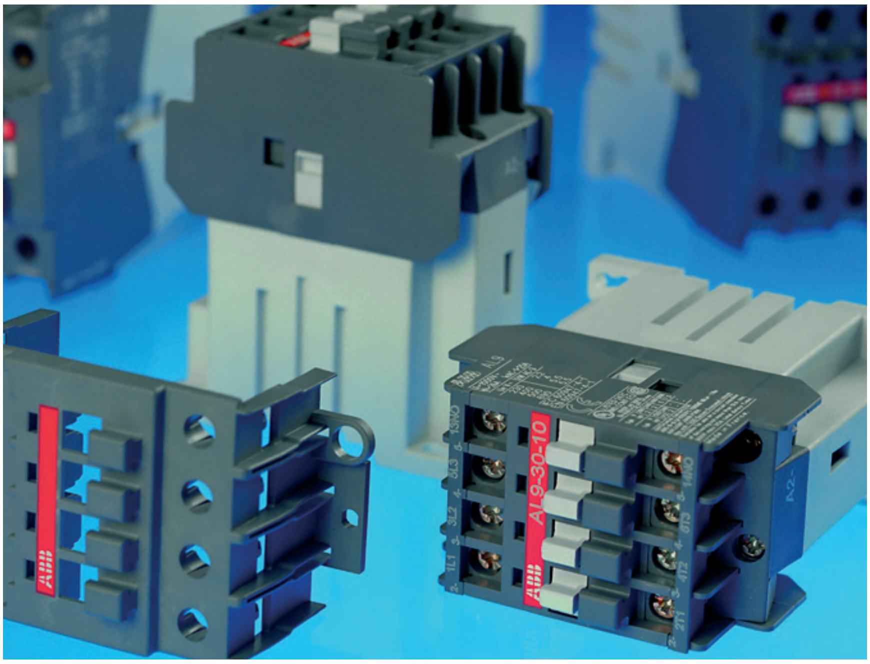

The ABB motor circuit breaker was developed specially for rail vehicles and is produced from halogen- and antimony-free, flame-retardant PBT

Plastics Go Electric

Electrical Engineering. In the globalised electrical industry, plastics are having to meet increasingly stringent, country-specific requirements. Flame-retardant modification plays a key role here.

KARL-MICHAEL REINFRANK
RALF NEUHAUS

Requirements for plastics in electrical engineering are becoming increasingly stringent. At the same time, the market is regulated by a multitude of different standards, which means that very special, flame-retardant-modified polymer materials must be available. High equipment and operating safety are top-priority assessment criteria for electrical goods. The most important requirement is comprehensive fire protection, for which there are many different regulations in Germany and other countries.

Market and Business Environment

As a result of the globalisation of the electrical industry, companies engaged in export activities have to comply with various different sets of regulations. On the back of simple electrical appliances such as chargers or power drills, the test marks of IEC, VDE, UL, DIN, GS, CE and other institutions often appear side by side.

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The approvals that lie behind the individual logos are costly and time-consuming to obtain and involve extensive work. Depending on the legal system and customer industry, different methods and assessment criteria are used for material and/or component testing.

Besides the specific regulations governing products, wider legislative trends also have an impact on the polymer laboratories of plastic suppliers. For example, environmental legislation prohibits the use of certain constituents or demands separate collection and recycling. Other demands are made on materials by processors, who – in addition to mechanical properties and processability – have costs in mind above all.

It is the task of an efficient engineering plastics supplier to find the right balance between these sometimes contradictory requirements and provide the optimum material for each end use. BASF supplies the right products for many different applications with its wide range of grades based on polyamide (PA), polybutylene terephthalate (PBT), polyoxymethylene (POM) and polysulfone/polyethersul-

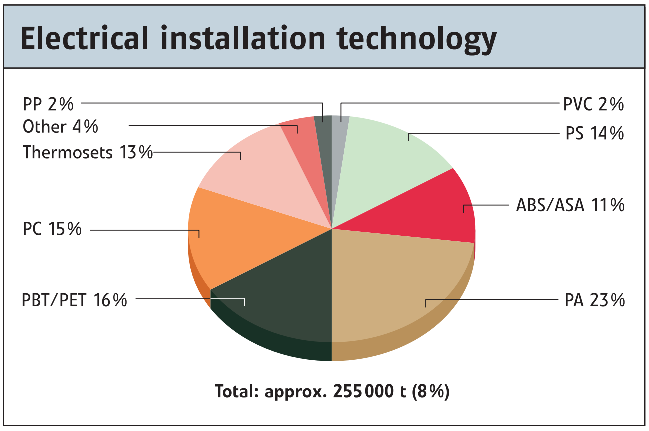


Fig. 1. Plastics consumption in the electrical industry in western Europe in 2000 (source: BASF)

fone (PSU/PES). The trade names under which BASF markets these four product groups are the so-called four ultras: Ultramid (PA), Ultradur (PBT), Ultraform (POM) and Ultrason (PSU/PES).

In 2000 alone, some 3 million t plastics were processed by the electrical industry in western Europe according to surveys by the VKE (German Association of the Plastics-producing Industry). With a 25 % share, Germany is the largest market, followed by Italy with 20 % and France with 17 %. Around 56 % of applications are accounted for by standard plastics, 35 % by engineering plastics and 9 % by thermosets. When the statistics are broken down by type of plastic, PVC dominates among the standard plastics with an 18 % share, followed by polystyrene (17 %), polyethylene (11 %) and polypropylene (10 %).

Breaking the statistics down by individual product sector, the following picture emerges for, e.g. electrical installation, which used 255 000 t plastics in 2000, accounting for some 8 % of plastics consumption. Activities here were dominated by polyamide (23 %) and PBT/PET (16 %). Double-digit shares were also achieved by polycarbonate, polystyrene, ABS/SAN and thermosets (Fig. 1).

Fire Behaviour Standards

The requirements these plastics have to meet are described in the relevant standards for electrically operated appliances and equipment. The measures set out in these standards not only affect the material itself but also contain specifications for component design. For example, the use of plastics with low flammability and flame spread on the one hand and the restriction through component design of the maximum temperature that can occur in an emergency on the other ensure optimum protection of life and property. In Europe, the regulations of the International Electrotechnical Commission (IEC) have become established in this area. Through European standards (EN), these have been adopted in German national legislation, leading to DIN and VDE standards. The situation is different

Glow wire test

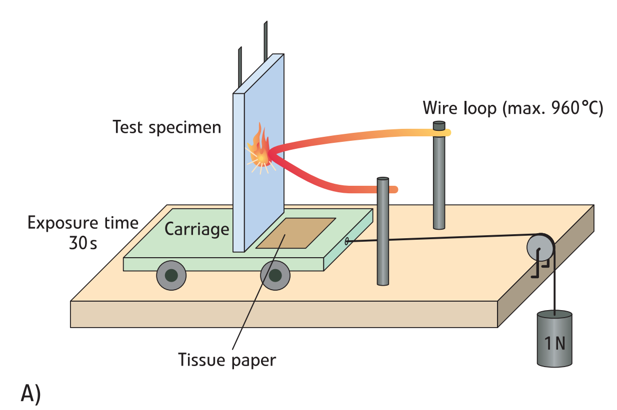
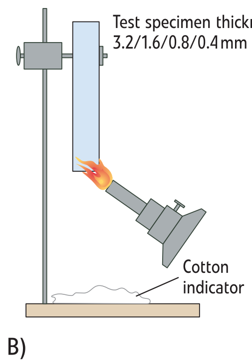


Fig. 2A. Standard IEC 60695 evaluates the glow wire temperature

UL 94 flame classifications



Classification	Burning time per flame exposure	Burning time after 10 flame exposure	Ignition of the cotton indicator
V 0	≤ 10 s	≤ 50 s	No
V 1	≤ 30 s	≤ 250 s	No
V 2	≤ 30 s	≤ 250 s	Yes

HB: Horizontal specimen
Burning rate ≤ 75 mm/min
FMVSS (Federal Motor Vehicle Safety Standard)
≤ 100 mm/min

Fig. 2B. The result determines assignment to flame classifications V (vertical) and HB (horizontal)

Hot wire ignition test (HWI)

Time to ignition (s)	PLC (Performance Level Category)
t > 120	0
60 < t < 120	1
30 < t < 60	2
15 < t < 30	3
7 < t < 15	4
0 < t < 7	5

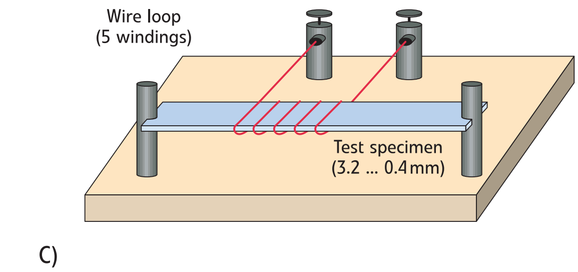


Fig. 2C. The test simulates ignition that can occur as a result of overheated wires

High-current arc ignition test (HAI)

Number of arcs	PLC (Performance Level Category)
n > 120	0
60 < n < 120	1
30 < n < 60	2
15 < n < 30	3
0 < n < 15	4

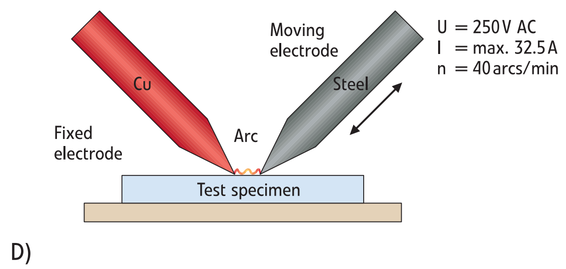


Fig. 2D. In the test, the test specimen is exposed to regularly repeating arcs between two electrodes (source: Underwriters Laboratories Inc.)

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in the USA, where the regulations of the Underwriters Laboratories (UL) apply, and in Canada, which is governed by the safety regulations of the Canadian Standards Association (CSA).

Among the most important standards for the electrical industry, governing industrial control equipment, are IEC 60947 in Europe and UL 508 in the USA. The design of circuit breakers for domestic electrical installation is regulated by IEC 60898 (Europe) and UL 1077 (USA). In the area of domestic appliances, the revised regulations IEC 60335 (with 85 subsidiary standards) and UL 60335 further tighten fire behaviour requirements. For special applications, such as rail vehicles, special standards such as the familiar French NF 16101 can be important.

Individual sets of regulations differ in terms of the specific requirements, testing scope and test methods for fire behaviour. The principles for material approval and component approval are to some extent in conflict here. UL base their standards firmly on material testing and documentation of material properties using a so-called yellow card. They summarise the requirements for plastics in the basic document UL 746 C (Polymeric materials – use in electrical equipment evaluations). In the area covered by the IEC standards, on the other hand, approval is based either on testing the material or testing the finished component, depending on the application. If designers rely solely on component testing, they can sometimes be in for a nasty surprise on completion of development work and implementation of some – perhaps only marginal – design modifications. If, on the other hand, approval is based on material characteristics, designers will meet the fire standards for each component made from this material.

Testing Fire Behaviour

Whether testing is conducted on test specimens or finished components, fire behaviour is an essential part of the test program. Different test methods are used to measure flammability, flame spread (self-extinction), contribution to heat evolution and development of fire gases and smoke. In all the tests, specification of the ignition source and way in which the test specimen is exposed to it is a common feature. Among the important test methods for components is the glow wire test (IEC 60695). In this test, a glowing resistance wire loop simulates overheated or red-hot metal parts. The wire, heated to the prescribed test temperature of between 650 and 960 °C, is pressed against the test moulding. Note is taken of whether the specimen catches fire, how long it burns and whether burning material drips down (Fig. 2A)

Fig. 4. Motor circuit breaker (small) and contactor (large). For the black housing part of the motor circuit breaker, Siemens uses a polyamide 66 with a red-phosphorus-based flame retardant system. In the large switch, the PA 66 is combined with a thermoset; the light-coloured covers are produced from flame-retardant, glass-fibre-reinforced PA 6 and laser-markable PBT

Material requirements for the electrical & electronics industry

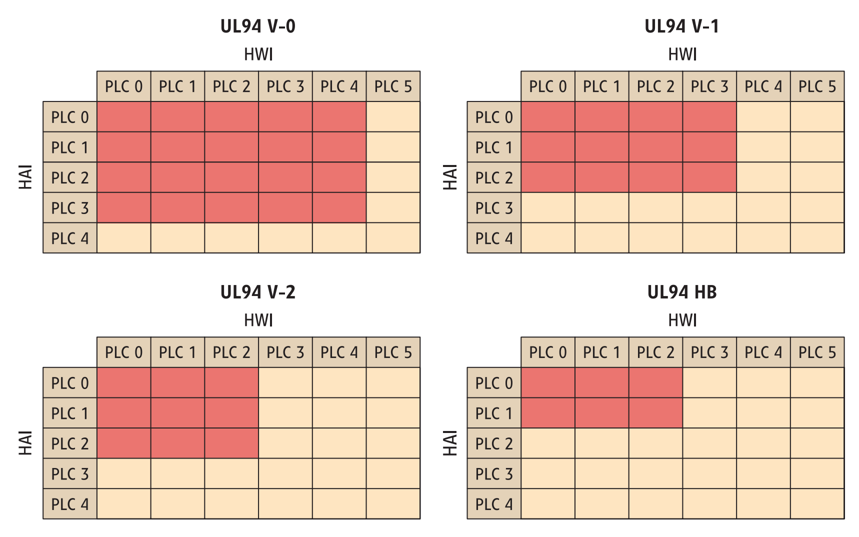

Fig. 3. UL 746C approval is gained through a combination of the UL 94 flame classification (V0 to V2) with HWI and HAI values. (The red fields represent approved combinations and the beige fields combinations not approved)

In the area of material testing, a flame exposure test (UL 94) is extremely important. The ignition source used is a bunsen burner flame, to which the test specimen must be briefly exposed twice. Then the burning time is measured and dripping of burning particles is evaluated using a cotton indicator placed under the test specimen. The result of this test is the familiar flame classification V (UL 94 vertical, and horizontal, HB; Fig. 2B). The flame exposure test should always be assessed in conjunction with the HWI (hot wire ignition test) and the HAI (high-current arc ignition test). The HWI simulates ignition that can occur as a result of an overheated wire. In the test, electrically heated resistance wire is wrapped around a horizontally positioned test bar. The evaluation criterion is the time it takes for the specimen to ignite. In the HAI test, the test specimen is exposed to regularly repeating electric arcs between two electrodes. The HAI measures the number of arcs until ignition occurs. Classification is in steps from 0 to 4, with 0 being the best rating (Figures 2C and 2D). Fig. 3 shows approved combinations of flame classification, HWI and HAI test results (red = approved according to UL 746C; beige = not approved).

Possible Ways of Achieving Effective Fire Protection

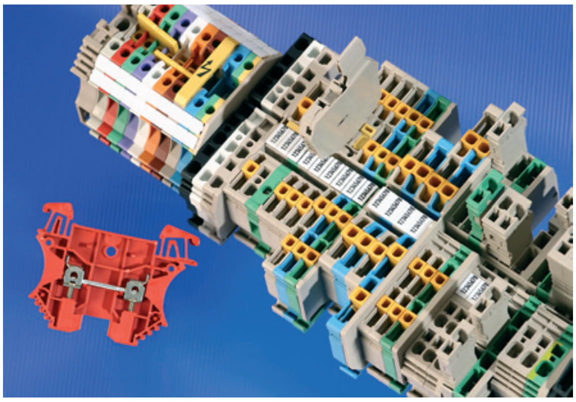

Fig. 5. The terminal blocks made by Weidmüller are produced from an unreinforced PA 6/PA 66 copolyamide modified with a halogen-free, nitrogen-based, flame retardant system that meets the requirements of flame classification V0

The fire behaviour of the different engineering plastics varies widely. Melting point gives no clue. It is only important for the production process. A more relevant criterion is the Low Oxygen Index (LOI), which specifies the oxygen content in the atmosphere at which the material just ceases to burn. For polyamide and PBT, the LOI is about 24. In both cases, suitable flame retardants can be found that increase the LOI. With an LOI of 15 for example, POM is relatively flammable. POM is therefore used for functional parts that have special requirements in terms of dynamic friction and spring properties but are not under electric current. POM formulations with flame retardants have a number of processing and application disadvantages and have so far found no market. The high-performance plastics polysulfone and polyethersulfone have LOI values between 30 and 38. They are non-flammable in a normal atmosphere and can generally be used without additional fire protection.

The aim of flame-retardant modification is to interfere with or delay the individual steps in the combustion process with the aid of flame-retardant additives and to reduce thermal feedback. There are several possible ways of doing this. However, only additives that have a negligible adverse influence on processability, mechanical properties or yellowing can be used.

Among the universally usable flame retardants are halogenated substances, including bromine-containing compounds. However, the EU Waste Electrical and Electronic Equipment directive (WEEE) specifies that plastic parts with bromine-containing flame retardants must be recycled separately. The additional costs associated with this will cause the market to move in the direction of halogen-free flame retardant systems.

These alternative flame retardants are usually just as effective as the halogenated but not so universally usable. Rather it is the case that halogen-free flame retardants must be tailored to the particular plastic. However, halogen-free flame retardants have less of an adverse effect on the electrical properties of components and, unlike halogenated additives, only increase the density of the material to a small extent.

For polyamides (PA), flame retardants based on red phosphorus are often used. The enormous importance of phosphorus-modified PA in the electrical industry – especially for electrical insulation components and housings in energy technology – is due to its excellent insulating properties (volume and surface resistance) coupled with good dielectric strength, tracking resistance and heat aging behaviour, and favourable bulk prices. The amounts of red phosphorus added tend to be small and so the good toughness/rigidity ratio typical of polyamide is retained. However, because of the inherent colour of red phosphorus, only red or dark-coloured components can be produced. In particular, the light grey widely employed in electrical installation cannot be obtained with plastics that have been flame-retardant-modified with red phosphorus. As an alternative to red phosphorus, flame resistance can be achieved with organic nitrogen compounds or magnesium hydroxide. A more recent development involves the use of organic phosphorus compounds as flame retardants. The advantage of this product class is that the new phosphorus compounds make it possible to produce light-coloured components. These flame retardants are however still very expensive. At the present time, it is difficult to assess whether the market will accept the products. Table 1 shows some properties of flame-retardant-modified plastics from the BASF range.

Fig. 6. This line circuit breaker is manufactured by Moeller from a light grey, flame-retardant polyamide

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Right Fire Protection for Every Application

For use in motor circuit breakers, two different polyamide grades are combined. For the black lower half, a glass-fibre-reinforced polyamide 66 modified with red phosphorus is used, which tolerates even high voltages and temperatures because of its flame retardancy. In addition it has a high heat deflection temperature and good mechanical properties. The light grey, visible side of the motor circuit breaker, on the other hand, does not require such a high fire rating, since there is no contact with live parts. This top part can therefore be produced from glass-

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Trade name	Polymer	Reinforce-ment	FR	FR class	HWI	HAI	GWFI °C	GWIT °C	Elastic modulus	Elongation at break %	Density g/cm³
Ultradur B4406 G6	PBT	GF30	Halogen	V0	0	0	960		11300	2.3	1.65
Ultradur B4400	PBT	Glass-fibre-reinforced	Halogen- and antimony-free	V0	2	0	960	725	11000	1.9	1.62
Ultramid C3U	PA 66/6	–	Halogen- and phosphorus-free	V0	2	0	960	960	3600 (tr)	6.0 (tr)	1.16
Ultramid A3X2G7	PA 66	GF35	Red phosphorus	V0	1	0	960	800	11000 (tr)	3 (tr)	1.45
Ultramid B3UG4	PA 6	GF20	Halogen- and phosphorus-free	V2	2	0	960		6000 (tr)	3.5 (tr)	1.31
Ultramid B3UM4	PA 6	M20	Halogen- and phosphorus-free	V2	3	0	960		5400 (tr)	3.0 (tr)	1.35
Ultramid B3UGM210	PA 6	GF10	Halogen- and phosphorus-free	V0	2	0			11000 (tr)	1.7 (tr)	1.67
Ultrason E2010G6	PES	GF30	–	V0					10200	1.9	1.6

Table 1. Properties of flame-retardant plastics in the BASF range

fibre-reinforced PA 6 modified with a nitrogen-containing flame retardant system or from PBT (Fig. 4).

Another application involves terminal blocks such as are used in large control cabinets. For the snapfits that facilitate assembly, toughness is more important than strength. In this application an unreinforced PA 6/PA 66 copolyamide with a halogen-free, nitrogen-based flame retardant system has proved very suitable (Fig. 5).

For line circuit breakers (Fig. 6), thermosets and polyamide modified with halogenated flame retardant systems are now being replaced by halogen-free products. A glass-fibre-reinforced PA 6 variant has been supplied for this application for quite some time. It is easier to process and offers a better price/performance ratio than conventional products.

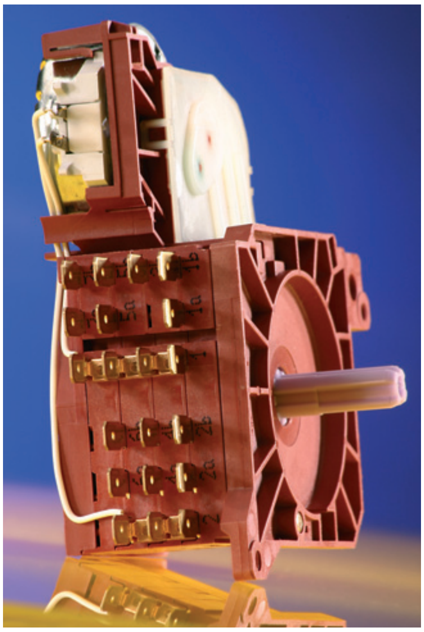

Fig. 7. The red-coloured parts of this program selector switch made by Diehl-Ako are produced from PA 66 modified with a phosphorus-based flame retardant; the white parts are also manufactured from PA 66

For household appliance switches, glass-fibre-filled PA 66 with a red phosphorus flame retardant system has typically been used (Fig. 7).

A new product in the BASF range is a mineral-reinforced PA 6 with a halogen-free flame retardant system. Intended for less highly stressed applications, this grade provides around 80 % of the mechanical property profile of glass-fibre-reinforced polyamide and at the same time offers customers high potential for cost reduction. And finally, with the use in serial production of the first flame-retardant PBT that is halogen- and antimony-free, an innovative polybutylene terephthalate from BASF has passed its baptism by fire. The ABB company is using Ultradur B4400 from BASF (exhibited at K 2001) in motor switches that are specially designed for high stresses in rail vehicles and comply with the strict French standard NF 16101 for this sector (title picture).

Meeting the Necessary Requirements

In the harsh competitive environment of the electrical industry, the cost aspect is becoming increasingly important, not only for polymer producers but also for plastics processors and component developers. The extensive and sometimes complex network of standards and regulations must therefore be carefully studied so that the plastic used meets all necessary but not all possible requirements. Only in this way can all those involved in the process develop optimum products in the long term. ■

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