How Suitable Are PA and PBT for High-Voltage Applications?

Against the Current

Electromobility in particular, but also many other electrical applications, are asking for ever higher demands regarding the electrical properties of thermoplastics. This raises the question of whether the polymers commonly used in this area can still meet these demands. The plastics manufacturer, Lanxess, has now investigated how suitable, for example, polyamide and polybutylene terephthalate are for use at higher voltages and temperatures.

Thermoplastics are established materials as electrical insulators in electrical engineering and electronics (E&E). The main reasons for this are that they satisfy the common demands for electrical and fire protection component safety, while also being cost-effective. For example, they exhibit good electrical and mechanical properties – often over a wide temperature range. Their long-term thermal stability is sufficiently high for very many applications. When combined with flame retardant additives, they offer good flame resistance. The good flow properties of their melt and their processing behavior make it possible to produce parts cost-effectively in large series by injection molding or extrusion.

Polyamide 6 (PA6), PA66 and polybutylene terephthalate (PBT) based compounds, in particular, have been used in the E&E sector for decades. Typical applications include connectors (**Fig. 1**), electronic housings, circuit breakers and terminal blocks. Both material classes are good insulators at room temperature (10^{15} and 10^{16} Ωcm, respectively) and are characterized by high dielectric strength and tracking resistance. The electrical properties of PA6 and PA66 are temperature and humidity dependent, however this is of little relevance for a wide range of applications. The electrical properties of PBT, on the other hand, remain almost constant over a wide temperature range. Also, and unlike PA, PBT absorbs practically no moisture from the environment. PA and especially PBT have very good long-term thermal stability of their electrical properties.

More Stringent Demands, Particularly in Electromobility

However, both classes of thermoplastics have recently had to face tougher and, in some cases, new challenges. This is particularly true for use in electromobility, including the associated charging infrastructure. In this area, components are exposed to very strong currents and high voltages at enhanced temperatures. They must remain electrically insulating even under these conditions and must not allow tracking to occur. Added to this is the fact that in electromobility – as in the classic E&E sector, in consumer electronics and household appliances – the trend towards miniaturized assemblies with the same or even higher performance is continuing. One consequence is that components are subjected to greater heat loads and the risk of defects due to leakage currents or electrical breakdown increases.

Lanxess has taken these new demands as an opportunity to investigate – using compounds from its Durethan (includes PA6 and PA66) and Pocan (PBT) product families – how important electrical properties such as volume resistivity or dielectric strength depend on temperature, moisture content and wall thickness. Here reinforced and non-reinforced compounds, with and without flame retardant packages, were considered. The study also investigated which compounds of the product families achieve the highest insulation class (CTI 600). Furthermore, the tracking resistance was determined after heat aging and aging under standard climatic conditions. The investigations also addressed the question of how components in high-

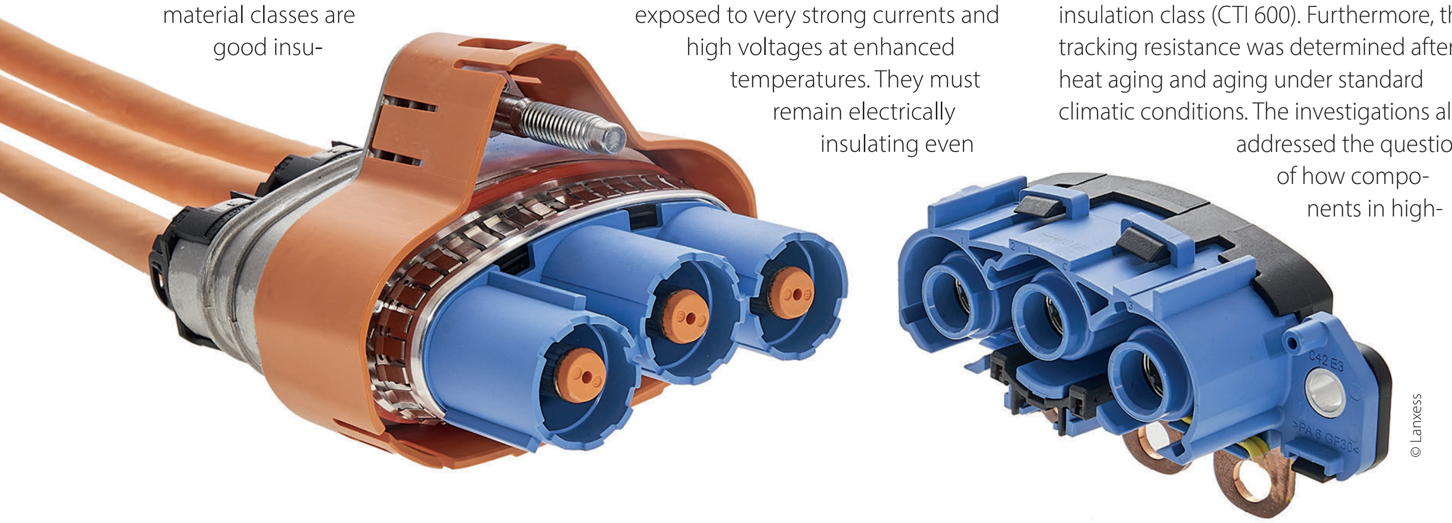

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Fig. 1. High-voltage connectors are a typical application for PA6, PA66 and PBT compounds. © Lanxess

voltage systems of electric vehicles, for example, which are frequently exposed to voltages of over 600 V, can be designed to withstand tracking currents based on the dimensioning guidelines defined in the IEC 60664-1 standard. Overall, the analyses aimed at providing customers with material recommendations and support for the design of electronic components subject to particularly high electrical stresses.

Temperature Influences the Volume Resistivity

The tests on volume resistivity of the compounds were carried out in accordance with IEC 62631–3–1 on freshly molded test specimens with a thickness of 1 mm. The volume resistivity is defined as the quotient of the applied electrical voltage and the measured amperage between two electrodes or live parts. The material-specific parameter is the volume resistivity ρ (Ωcm) which corresponds to the reciprocal of the electrical conductivity and is used to classify materials into the categories of insulators, semiconductors and conductors.

The tests show that the volume resistivity of the compounds decreases with increasing temperature, although this effect is much less pronounced for PBT (**Fig. 2**). There are no significant differences between compounds without flame retardant and those with halogen-free flame retardant packages. PA6 and PA66-based compounds still achieve a volume resistivity of 10^8 Ωcm even at 140 °C in the dry-as-molded state. They thus meet the standard demands made on plastics for use in high-voltage systems up to this temperature. The volume resistivity of PBT is significantly higher at this temperature.

Is the High Moisture Absorption of PA a Problem?

Increasing moisture content causes the volume resistivity of PA6 and PA66 compounds to drop. Unfilled as well as glass fiber-reinforced products with and without flame retardants behave very similarly. A significant decrease in volume resistivity is evident at room temperature (**Fig. 3**). It levels off, however, at values that are not critical for most applications. At higher temperatures, the decrease is less pronounced in relative terms, but the values are at a lower level overall. The volume resistivity could thus fall below the minimum volume resistivity of 10^8 Ωcm recommended for high-voltage applications. In this case the material no longer has a sufficient insulating effect. As such high temperatures always result in a re-drying of hygroscopic materials, however, this occurs only very rarely and under extremely unfavorable conditions in practice. The specific volume resistivity of PA66 compounds decreases less with increasing moisture content compared to their PA6 counterparts – at 23 °C by about one power of ten.

High Electric Strength, Smaller Components

The electric strength E_d (kV/mm) of the compounds was investigated on freshly molded test specimens in accordance with the IEC 60243–1 standard. It is defined as the electric field strength at which a material just does not lose its electrical insulation properties. In the event of material failure or electric breakdown, an arc or spark can be detected. The electric strength depends, among other things, on the ambient temperature, the moisture content of the material, the thickness of the test specimen and the type of current (DC or AC). It helps to determine how small the distance between »

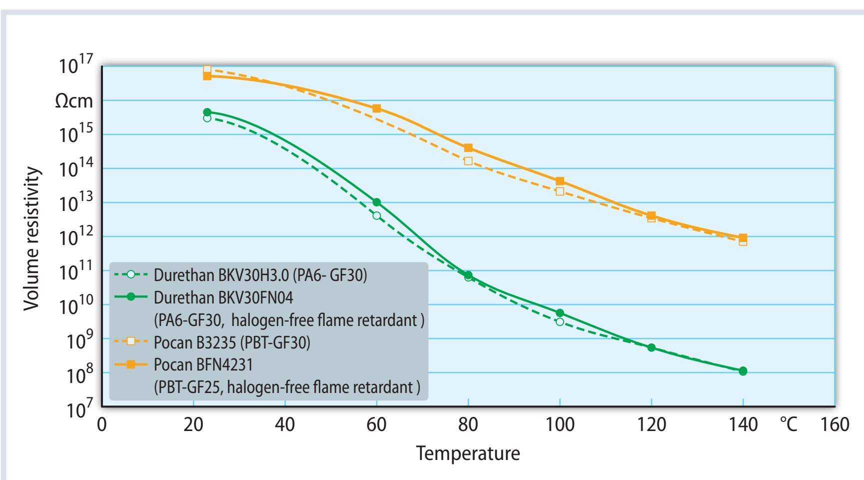

Fig. 2. Temperature dependence of the volume resistivity of glass fiber-reinforced PA6 and PBT compounds: the volume resistivity of PBT drops less sharply than that of polyamide at higher temperatures. Source: Lanxess; graphic: © Hanser

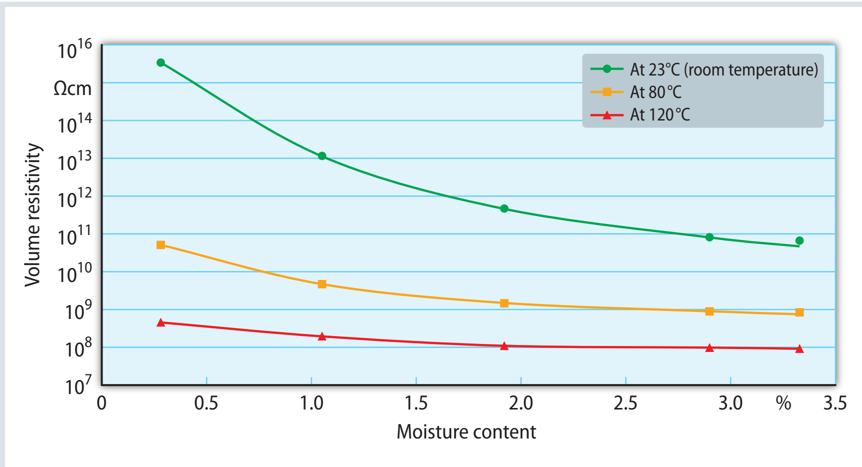

Fig. 3. Dependence of the volume resistivity on the moisture content, taking the example of a PA6-GF30 (Durethan BKV30H3.0): the higher the moisture content, the lower the resistivity. The volume resistivity after moisture absorption drops more sharply at room temperature than at higher temperatures. Source: Lanxess; graphic: © Hanser

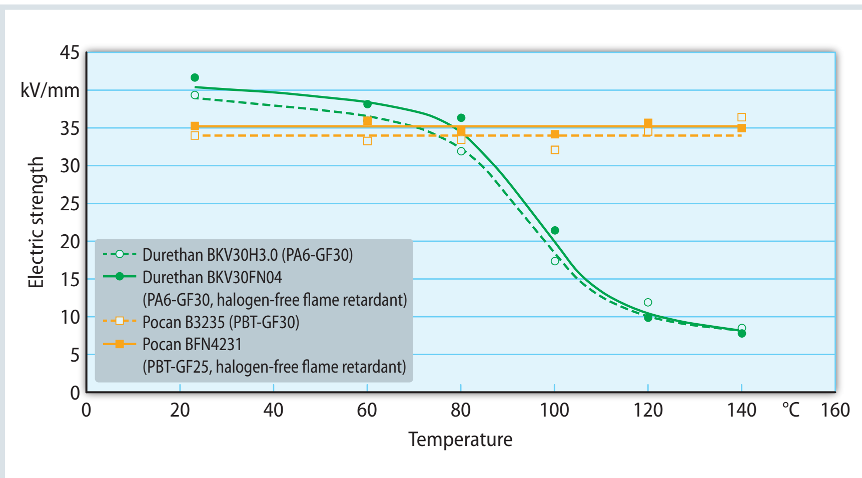

Fig. 4. Temperature dependence of the electric strength of glass fiber-reinforced PA6 and PBT compounds: PBT exhibits practically no change over the whole temperature range. With PA, however, a significant drop is to be observed above approx. 80 °C. Source: Lanxess; graphic: © Hanser

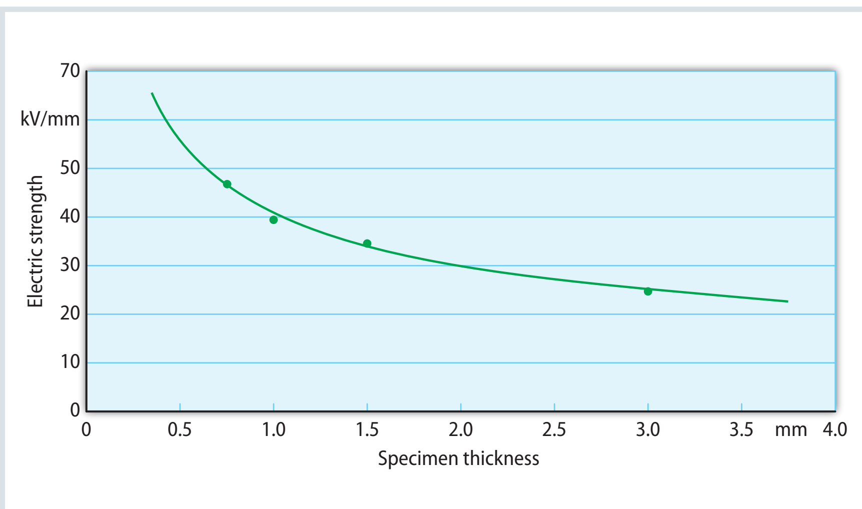

Fig. 5. Dependence of the electric strength on the specimen thickness for a PA6-GF30 (Durethan BKV30H3.0) at room temperature: the electric strength decreases sharply with increasing thickness. This is attributable in particular to the better heat dissipation with small wall thicknesses.
Source: Lanxess; graphic: © Hanser

live elements in a component may just be at a given voltage while still avoiding an electric breakdown. Materials with high electric strength are needed, for example, to make high-voltage connectors as space-saving as possible.

The measurements show that the electric strength of PA6, PA66 and PBT compounds with a specimen thickness of 1 mm behaves completely differently under the influence of temperature. In the case of PBT compounds it remains almost constant or unchanged at a high level up to 140 °C. For PA compounds, on the other hand, it decreases significantly from a high level at room temperature as the temperature rises (**Fig. 4**). For PA6 and PA66 compounds in the dry-as-molded state, however, the electric strength drops below a value of 10 kV/mm only above 120 °C, and thus also meets the high minimum requirements for materials for high-voltage applications at typical operating temperatures.

The measurements also showed that – by contrast with the volume resistivity – the electric strength of the compounds depends significantly on the wall thickness. It decreases significantly with increasing specimen thickness (**Fig. 5**). The reason for this is that heat can be dissipated better with thinner wall thicknesses, thus delaying heating and preventing premature electric breakdown. This behavior, which is also characteristic of other plastics, favors the miniaturization of components.

High Tracking Resistance Becoming Increasingly Important

Tracking resistance indicates how well a material resists the formation of conductive creepage paths on the surface when exposed to high voltage and contamination. The higher the tracking resistance, the lower the risk of short circuits. The characteristic value of the tracking resistance is the comparative tracking index (CTI, IEC 60112). It is determined by gradually trickling drops of a standardized electrolyte test solution onto a test specimen between two live electrodes. CTI A is the highest voltage value at which no failure occurs on five specimens after 50 drops.

		PA6 & PA66	PBT
Without flame retardant	Non-reinforced	CTI 600	CTI 600
	Reinforced	CTI 400-600	CTI 275-550
With halogen-containing flame retardant	Non-reinforced	CTI 250-400	CTI 250-600
	Reinforced	CTI 400-550	CTI 175-300
With halogen-free flame retardant	Non-reinforced	CTI 600	CTI 600
	Reinforced	CTI 500-600	CTI 425-600

Table 1. Typical CTI values for compounds of PA6, PA66 and PBT. Source: Lanxess

The CTI value depends mainly on the chemical polymer structure, the charring behavior of the polymer, the temperature, the surface tension and roughness of the material surface, and the type of plastic pigmentation and additives. The CTI value plays a major role particularly in the production of printed circuit boards, because the distances between electrical contacts (pins) are becoming smaller and smaller, making a tracking resistant carrier material necessary. But high CTI values are also essential in many other E&E and electromobility applications that require high surge voltage protection.

In general, halogen-free as well as non-flame retardant PA6, PA66 and PBT compounds have higher CTI values than compounds with halogen-based flame retardant packages (**Table 1**). Higher CTI values can also generally be achieved with non-reinforced compounds rather than with reinforced compounds. The moisture absorption of PA compounds has no measurable influence on their CTI value or their tracking resistance, respectively. The investigations also showed that the CTI value of the compounds hardly changes after heat aging at 120 °C or aging under standard climatic conditions. They therefore remain reliably creep-resistant even after aging.

CTI Measurements at above 600 V Make No Sense

The increasing voltages in many electromobility applications raise the question as to whether CTI values of plastics should not be measured at voltages higher than 600 V, too. There are several reasons not to do so. For example, the electrolyte solution trickled onto the specimen in the test procedure tends to evaporate at the temperatures generated by higher voltages. That falsifies the measurements. Furthermore, electrical discharges through the air can occur on the surface of the specimen at voltages of more than 600 V. These also influence the measurement.

Guideline for Component Design at Higher Voltages

The CTI test is essentially a test method for direct comparison of materials under standard conditions and should not be directly linked to the operating voltage of the application, because a CTI value of 600 does not mean that a material cannot be used at voltages higher than 600 V. The IEC 60664/VDE 0110–1 standard provides guidance on this subject. It defines design guidelines that can be used to "translate" the CTI test result and to optimize the component design for higher voltages.

The standard applies to components used at a nominal voltage of up to 1000 V in the case of alternating current, at frequencies of up to 30 kHz, or a nominal voltage of up to 1500 V in the case of direct current. The basis for determining minimum creepage distances and minimum clearances in the planned component is a flow diagram that takes into account several variables. These include the insulating material group into which the material in question falls according to its CTI value, the nominal voltage range, the nominal surge voltage and the degree of contamination determined by the installation location of the component. For a high-voltage connector (**Title figure**) used at a nominal voltage of 800 V, the design guidelines and the flow chart result in a minimum creepage distance of 4 mm at a level 2 degree of contamination if a material with a CTI value of 600 is used for it.

Conclusion

The investigations resulted in the following recommendations for high-voltage components, such as those used in electric vehicles: PA6 and PA66 compounds can be used up to 120 °C due to the temperature and humidity dependence of their electrical properties. PBT compounds, on the other hand, maintain their electrical properties at temperatures of up to 150 °C. If an application requires high tracking resistance, compounds with CTI values of 600 are available for this purpose in both thermoplastic classes. These can also be used for applications with higher voltages than 600 V. The tracking resistance of both compound families hardly decreases even after long-term aging at 120 °C. ■

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Further information on the investigations described and on numerous PA and PBT compounds from Lanxess can be found in the technical brochure "Electrical properties of Durethan and Pocan" that can be downloaded at ***https://techcenter.lanxess.com/scp/emea/en*** under the menu items "Library" – "Technical Literature"

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