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RELATIVE POSITIONING OF CARILON POLYMER IN THE ELECTRICAL AND ELECTRONIC MARKET SECTOR

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(August 1992 - August 1993)

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Approved by: J.A. Verhave

SUMMARY

A substantial share of the engineering thermoplastic (ETP) market consist of electrical and electronic (E/E) applications. Miniaturisation in E/E applications is the driving force for using ETP's in this sector with specific requirements for electrical properties, flame-resistance, heat resistance and dimensional stability.

An inventory of the major performance requirements for E/E applications indicate that the temperature requirements for the electronic sector are too severe for the current CARILON polymer. Its good ultimate electrical properties (especially its comparative Tracking Index, CTI) gives CARILON polymer a potential in the electro-technical sector. It can be compared to the major player in this sector, polyamide 66, with the advantage of possessing a better dimensional stability but at a somewhat lower continuous use temperature.

A more precise definition of the edge of CARILON polymers in the E/E sector can only be given on the basis of flame retardant compounds. The challenge is to come up with halogen and red phosphorous free flame retardant systems which meets the same level of electrical, mechanical and thermal properties, especially in glass filled compounds. For glass filled polyamide or poly(butylene terephtalate) such systems are not available. Current FR developments for CARILON polymer, based on a.o. magnesium hydroxide, yield good property retention and may offer clear advantages in electronic components, connectors and electrical assemblies. Depending on the specific UV requirements, electrical housings also present a potential application area. To establish the value of CARILON compounds in the E/E sector, a close and intense cooperation with leading part-manufacturers is considered essential.

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IN THE ELECTRICAL AND ELECTRONIC MARKET SECTOR**

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1   INTRODUCTION

A substantial consumption of engineering thermoplastics (ETP's) takes place in the electrical and electronic (E/E) applications. The use of CARILON polymer in this market sector is still a terra incognito. To successfully develop CARILON polymer in the E/E market, it is necessarily to identify its edge c.q. its value in this market sector. Based on a literature survey, the current report tries to identify the key applications in this sector and to balance the corresponding necessary material properties. The final goal is to set a frame work for the application development in this sector.

The share of ETP's in the E/E market is given in chapter 2. Important electrical properties are discussed in chapter 3. For a more detailed description of these properties including their corresponding test methods, the reader is referred to Appendix 1. Chapter 4 contains a positioning of CARILON polymer in terms of its electrical properties, based on an a preliminary inventory. The major electronic and electrical applications and their corresponding principal performance requirements are discussed in chapters 5 and 6 respectively. Based on these requirements and the corresponding material properties, CARILON polymer and its competitors are balanced amongst each other (chapter 7). The report is concluded by an outlook of the CARILON polymer application development programme for this sector (chapter 8).

2   THE ELECTRICAL AND ELECTRONIC MARKET FOR ENGINEERING THERMOPLASTICS

Electrical and electronic (E/E) applications of engineering thermoplastics (ETP's) are in principal all applications having an electrical or electronic function. Mainly all E/E applications are related to electrical insulation. In electro-technical parts, ETP's are used in plugs, sockets, switches, fuse boxes, switching/wire cabinets etc. In electronic components, they are applied in circuit boards and connectors. With respect to electronic applications one sometimes also uses the term "teletronics", covering a large field of applications, from "circuit board and the chips/components that are mounted on it, through to the finished items of equipment that rely on electronics to function" [1]. Typical market sectors for polymers in this respect are business machines, consumer electronics and telecommunications.

The share of the E/E applications in the ETP market is substantial. In a classification of the 1989 ETP market by IAL Consultants [2], 10.0% of the total European ETP consumption is used for E/E applications (165 kt) and 5.3% for business machines and computers (88 kt). Besides this the consumer appliances and automotive market consist of a large number of applications where E/E requirements are essential (e.g. housings).

The average annual growth in the W-European E/E market through 1994 is expected to be 5.4% [2]. An impression of the growth within the different segments of the E/E market can be obtained from the forecast grow figures given for the Western part of Germany, as is given in Table 1 [3].

The share in the 1989 W-European market of the ETP's in the E/E sector and their expected growth are given in Table 2. By examining the share of the major competitors, i.e. polyamide (PA), poly(butylene terephthalate) (PBT), polyacetal (POM) and polycarbonate (PC), the importance of the E/E sector can even be more emphasised. From the total consumption of PA66 in ETP applications, 28% (45 kt) is used in the E/E sector. For PA6 this is 26% (42 kt), for PBT 38% (10 kt), for PC 15% (21 kt) and for PA11/12 10% (2 kt).

Only 5% (5 kt) of the total POM consumption is used in the E/E market. In fact the share of ETP's in E/E-type of applications is higher than classified in the E/E sector. From the total consumption of polyamides in the automotive sector, i.e. 98 kt, 15 - 20 kt is used for E/E applications [2].

3   ELECTRICAL PROPERTIES

For the sake of convenience, one can make an analogy between electrical properties and mechanical properties as is shown in Table 3 [4]. The major electrical properties are discussed in more detail in Appendix 1. Comments are added as to how these properties can be influenced and have to be tested according to the European plastic data bank system CAMPUS (Computer Aided Material Preselection with Uniform Standards).

Applying polymers in E/E applications, mostly as an insulator, means that it becomes part of the electrical circuit. The electrical system is thereby changed in two ways. Firstly, it introduces a power loss that can affect the ability of the circuit to function and secondly, it introduces a capacitive reactance that can alter the inherent electrical characteristics of the circuit.

In a low electric field, the electrical properties which govern dielectric loss and capacitance are the most important ones for material selection and design, i.e. relative permittivity or dielectric constant, dissipation factor or loss tangent, and resistivity. The latter is primarily important in direct current (dc) circuits while the first two are important in alternating current (ac) circuits [5]. These properties are intrinsic properties directly related to the chemical structure.

In a high electric field, for example in circuit breakers, switches and power connectors, dielectric strength, electric discharging, arc resistance and tracking become important electrical properties. These properties are no fundamental properties but a result of the method of determination [6].

In considering E/E applications, a specific set of electrical properties is important, but in many cases a particular level of flame-resistance, heat ageing resistance and dimensional stability are of prime concern. The failure mode will in most cases first of all be mechanical due to thermal degradation or environmental effects. In turn, mechanical or chemical failure will cause electrical failure [7].

4   ELECTRICAL PROPERTIES OF 'CARILON' POLYMERS

To make a judgement of the potential of CARILON polymers in E/E applications one should know for different grades, the electrical properties at different conditions (temperatures, frequency, moisture content etc.). (The FR systems necessary in many E/E applications , lower in general the ultimate electric properties i.e. dielectric strength and CTI.)

Sofar, a number of electrical properties were determined by Hoechst Celanese and MYKK [8]. These results are reproduced in Tables 4 and 5. The test methods for the latter are not known. Data of competitive ETP's, i.e. PA66, PBT and POM (all non-FR grades), have also been included. The CARILON EP polymer data generated are therefore useful as a relative measure. From a comparison of these data with the values given in the data sheets provided by the PA66 and POM suppliers [9], one can see that the general level of the values measured by MYKK is higher than those given in the supplier's data sheets. Furthermore, the values given for PA66, indicate that these are typical values for dry as moulded PA66 instead of PA66 conditioned to 23°C/50% R.H.

Taking this into consideration, these data suggest that the dielectric properties of CARILON EP polymer are more frequency dependent than dry-PA66, PBT and POM-copolymer. The surface and volume resistivity of CARILON EP polymer are lower than that of PBT and dry-PA66 but fall in the same range as that of POM.

Comparing the PA66 literature data [9] with the CARILON EP polymer data generated by MYKK, one obtains the picture that at room temperature the relative permittivity of CARILON EP polymer falls in the range of PA66 conditioned to 50% R.H. at 23°C. The dissipation constant is however distinctly lower than that of conditioned PA66. In this respect, the heat generated by an electric current as indicated by the loss index (see Appendix 1.1) in CARILON EP polymer is distinctly lower than in conditioned PA66.

The values for the resistivities are also more alike to those of conditioned PA66 as those of dry as moulded PA66.

The high CTI of 600 V measured by Hoechst Celanese was also confirmed by measurement at CRCSL [10] and in a customer evaluation [11].

The electrical properties of 30 wt% glass fibre reinforced CARILON EP polymer and similar PA66 and PBT grades, also measured by MYKK, are listed in Table 6. It is remarkable to see that in going from unfilled to glass filled CARILON compound, the relative permittivity decreases with an absolute value of about 1 for PA66 and PBT; it increases with a value of about 0.5. The reason for this is not clear. The decrease in dissipation factor for CARILON and to a somewhat lesser degree for PA66 and PBT, is in agreement with the decrease in polarity when adding glass fibres.

5   ELECTRONIC APPLICATIONS

Traditionally thermosets are used in electronic applications like printed circuit boards, components and connectors. The development of new technologies and high temperature resistant materials, open up the way to ETP's in this sector. In electronic engineering, the key trend for devices is to pack more power and to function into smaller, lighter weight and less costly packages [12]. This resulted in the development of three-dimensional circuit boards which created new soldering techniques. All this requires new materials, having a higher heat resistance, an improved dimensional stability and processing advantages.

This chapter provides a comprehensive overview of the main outlets in the electronic sector. For each outlet, the principal requirements, in terms of properties and mouldability, and the preferred choice of ETP's are mentioned. Also, the latest developments in the different areas requiring special features have been highlighted. The large impact of new soldering techniques on material requirements (i.e. temperature resistance) made it necessarily to treat it in a separate section.

5.1   Circuit Boards

Printed circuit boards (PCB) consist of conducting lines between components and contacts fixed to a insulating base board (usually an glass fabric containing epoxy base copper clad laminate).

Trends

The current trend, especially in the US, is to replace PCB's by injection moulded circuit boards from ETP's, allowing three-dimensional design features like snap fits, connectors, mounting points and resulting in a reduced size of the boards. By incorporating all kind of features to a moulded circuit board, the board can grow out to a 'moulded interconnecting device' [13]. Example are a pre-wired chassis developed for the use in plain paper copiers [14], parts for disk drives [16].

The moulded circuit board technology can be cost saving over flat board PCB technology. However, the technology is heavily patented and its licences are expensive [2]. Nevertheless it is expected that this technique becomes a dominant design and manufacturing technique within this decade [13].

Metallisation to obtain conducting lines and/or EMI shielding can be obtained by additive (electroless) plating processes using aqueous coatable UV photoimagable polymers or in-mould imaging (2-shots) moulding. In the latter, a plateable (catalysed, generally Palladium) resin is overmoulded during a second shot with non-plateable (non-catalysed) resin, followed by surface treatment and copper deposition onto the catalysed resin [13,16].

Requirements

Due to miniaturisation, such moulded boards require ETP's having a higher temperature resistance than the conventional used material. The upper service temperature of epoxy resins used in glass fabric based copper-clad laminates (NEMA grade FR-4) is about 130°C. Furthermore, High strength and stiffness, improved chemical resistance, excellent dimensional stability and low moisture absorbtion are needed.

Materials

Polyether imide (PEI) (continuous use temperature (CUT): 170°C) is the most used material in these applications because of its easy mouldability, good electrical properties and good temperature resistance with respect to reflow soldering techniques (see below). Polyethersulfone (PES) (CUT: 180°C) is also used due to its dimensional stability [13]. BASF already developed a PES grade containing a catalysts for in-mould imaging moulding [16]. Both PEI and PES posses an intrinsic flame resistance (UL 94 at 0.8 mm: V-0). In addition, being amorphous, both polymers give relatively stress free moulded parts. Besides PEI and PES, Polyarylsulfone (PAS) and liquid crystal polymers (LCP) are used. Generally, filled grades are used (milled glass, glass/mineral or mineral only).

5.2   Components

Applications for ETP's in the area of components lay in the encapsulation of electronic parts e.g. integrated circuits.

Requirements

Key requirements are impact resistance, tracking resistance, high dielectric strength, high volume resistivity and low relative permittivity. In case the PCB's are solvent washed (trichloroethylene and other cleaning solvents), the encapsulation should also be solvent resistant [2]. Other important material requirements are the absence of disruptive ions, inherent flame resistance and good mould flowability (even at high filling ratios) [3].

Furthermore, the material must have no tendency to generate charges itself. The components are otherwise susceptible to damage from electrostatic discharge. It is possible to eliminate such failure by using statically dissipative materials or conductive thermoplastic composites (carbon or steel fibres). On the other hand however, the material must preserve a high volume resistivity in order to prevent leakage of current between the leads or pins. From a mechanical point of view, sufficient resilience is required to deflect without permanent distortion for placement of package in the carrier. The material must also withstand the temperature during burn-in without distortion or outgassing [16].

Materials

Traditionally phenolics, epoxies and elastomers are used for component encapsulation. PBT-GF-FR is used for board mounted components (dual-in-line switches, edge connectors, sockets etc.). Its poor resistance against the traditionally used solvents makes it however not suitable for all cleaning solvents. PA appears to have sufficient solvent resistance and is being used in high volume consumer electronics [2].

Trends

In recent years, the developments in the component sector are very much driven by surface board mounted technology. The miniaturisation trend resulted in components with higher pin counts and board mounted components having a higher packing density, all yielding a significant rise in temperature stresses. In addition, the operating frequencies still increase (in microprocessors this can approach values of 100 MHz and in microchips 64 Mbits) [17]. The continuous service temperature increases so by 10 - 15°C over the last few years [18]. Furthermore, the use of reflow soldering techniques in surface mounted devices requires a higher short term temperature resistance (see below).

A material like glass reinforced polyphenylene sulfide (PPS-GF) has become very favoured in components due to the increased pressure on the short and long term temperature resistance.

5.3   Connectors

Opposite to power connectors and cable connectors for signals between associated pieces, connectors in electronics are becoming more and more complex. Together with the cable, they are forming a very vital link in the system and with that can be regarded as a very important component part of the electronic system. This implies that in choosing or designing a connector all signal characteristics have to be taken into consideration (voltage, current, impedance, allowable losses, degree of shielding) [19].

Requirements

General requirements for plug and socket connectors in electronic applications are [20]:

- rigidity and strength (E-modulus: 2 - 10 GPa),
- strain at break $\geq$ 3%,
- good electrical insulating properties (CTI),
- CUT: 100 - 120°C,
- heat distortion temperature supporting exposure for some seconds to 240°C (conventional soldering condition),
- short term resistance against trichloroethylene and other cleaning solvents,

- resistance to environmental stress cracking,
- dimensional stability,
- low thermal expansion i.e. $\leq 3.10^{-6} K^{-1}$,
- electrolytic corrosion effect below AN 1.4 (IEC 426),
- flame-resistance: UL 94 V-0 at 1.6 mm (or even 0.8 mm).

Materials

Traditionally, compression moulded thermosets were used for connectors. Their slow processing and brittle character favoured a replacement by ETP's. First of all PC and PA were used as replacement. Subsequently PBT and also poly(ethylene terephthalate) (PET) were used because of good mouldability, sufficient temperature resistance, better solvent resistance compared to PC and lower moisture sensitivity than PA [2,21].

Trends

As a result of the miniaturisation trend, connectors became in general the bulkiest part in electronic circuits. This resulted in the development of high density miniaturised connectors with unique geometric configurations. The following design and corresponding material performance requirements are important in this respect [12]:

- thinner walls, requiring improved flow,
- more insulating partitions, requiring improved dimensional stability (less moisture sensitive),
- more contacts per area (the connector spacing has dropped from an average of 2.5 mm to 1.3 mm), requiring improved electrical properties,
- snap-lock designs, requiring improved resilience,
- new processing techniques, requiring improved service temperature,
- competitive economics, requiring improved price/performance.

New materials

Materials which can take-up these new requirements are thermoplastic polyester alloys, higher flow PEI, high temperature filled polysulfone (PSU) alloys and special nylon grades.

An example of a new material to be applied is a specialty polyester, poly(1,4 cyclohexylenedimethylene terephthalate) (PCT); Ektar, ex. Eastman Chemicals and Valox, ex. General Electric Plastics). PCT is specially designed for surface mount technology. (The same shrinkage figure of PCT as that of PBT and PET, allows a change to PCT without tool change) [18].

Glass fibre reinforced polyarylamide (Ixef, ex. Solvay) is another example. It shows outstanding mechanical properties (comparable to metal alloys) e.g. tensile strength: 250 MPa, tensile modulus: 17 GPa and heat deflection temperature at 1.8 MPa loading (HDT/A): 230°C, low thermal expansion coefficient (comparable to metals), excellent creep resistance and dimensional stability, good electrical properties, intrinsic flame-resistance [18].

5.4   Other Electronic Applications

A number of application in the electronic sector are related to the construction of boards, components and connectors: board guides (phenolics, PBT, modified polyphenyloxide (PPO), PC), board stiffeners (phenolics), internal covers and supports (flame retardant low-cost materials like polyvinyl chloride (PVC), acrylonitrile-butadiene-styrene resin (ABS) and polystyrene (PS)) and brackets (glass fibre reinforced grades of PA, PBT, modified PPO) [2].

5.5   Soldering Techniques

Conventional

All electrical connections between components and circuit boards are made by soldering. The temperatures involved put the highest demand on the short term temperature resistance. In the conventional through-hole technology, soldering often takes place by wave soldering (exposure time to 220 - 260°C for 1 - 3 s). The components are thereby placed at some distance from the soldering point and are so shielded from excessive heat [1]. An indication of the resistance against through-hole soldering is obtained from the heat distortion temperature for a few seconds at 240°C, as given in Table 7 [20].

New techniques

The miniaturisation trend led to the development of a new soldering technique, viz. reflow soldering. With these technique it is possible to obtain lead spacings down to 0.5 mm [18]. The principal techniques are vapour phase systems (VPS) and infrared (IR) soldering. In VPS the temperature is fixed at 214°C for a typical period of 30 - 45 s (in some cases even 3 min). In IR soldering, temperatures reach values of 230 - 250°C for a period of 10 - 56 s [23].

VPS is generally applied in assembling mid to high complexity interconnect devices (e.g. as used in office equipment). High speed, low to mid complexity assembly of interconnects (as in a large number of consumer electronics) are mainly served by IR soldering [23].

VPS excludes all polymers having a melting point below 214°C. PBT is normally not considered to be resistant to VPS soldering. PET, having a slightly higher melting point than PBT is regarded as vapour phase solderable. The high temperature engineering polymers, like polyarylether ketone (PAEK), polyetherether ketone (PEEK), polyether ketone (PEK) and LCP's and some of the PA (including PA46), PSU grades and polyphenylether (PPE) blends are resistant to VPS and IR soldering.

6   ELECTRICAL APPLICATIONS

Similar as for the electronic sector, the main outlets for the electrical sector and corresponding requirements, preferred choice of ETP's and future trends are given.

The general requirements for a polymeric materials used in electrical equipment are written down in test standards like UL 746C. A classification for the temperature resistance of insulating systems is given in standard UL 1446.

6.1   Electrical Assemblies

Switches, breakers, power connectors, bobbins, coil formers and relays are all electrical parts which one could classify as electrical assemblies. Within each of them one can make a further subdivision, for example in switches, appliance switches, command switches, industrial switch gears, magnetic switches for functioning parts in command contractors, cam and limit switches. Each assembly has its own specific function and usage with corresponding set of requirements. To prevent a comprehensive discussion of every class of electrical parts, the accent is put on the main set of material requirements (electrical, mechanical, flame- and temperature resistance).

Requirements

In most assemblies, the ETP function as an insulator. In case it acts as an interface between voltage containing parts, the main requirement is its temperature resistance. This is measured in ball pressure tests (VDE 0470). In case it is supporting live parts (direct contact with 220 V), the temperature resistance in the ball pressure test should be at least 125°C. For parts which do not support current carrying parts, this is at least 75°C (in special cases, 85°C).

For uninsulated live parts, indoor and in a clean environment, the Comparative Tracking Index (CTI) should be at least 100 - 175 V. For outdoor and indoor equipment that may be exposed to moderate contaminate environments, this is at least 175 - 250 V. For equipment that is likely to be subjected to severe contaminating environments, a minimum CTI value of 250 - 400 V is required (UL 746C).

The glow wire temperature should be between 550 and 960°C, depending on the type of application (IEC 695-2-1, VDE 0471-2-1). For non-load bearing or external insulating parts the requirement is often 650°C and for load bearing parts 850 or 960°C (VDE 0632). The specific flame resistance requirements for a number of electrical applications are measured according to VDE 0304 or UL 94 [24]. For live parts this is most of the time a UL 94 (at 1.6 mm) flame resistance requirement of at least V-2 or more severe V-0 or even 5V.

Besides the general requirements which are specifically defined for every type of assembly, requirements dealing with their function and usage, i.e. thermal, mechanical, electrical and chemical, should also be taken into account.

Materials

Dominating ETP's in this market segment are PA and PBT compounds (especially glass fibre and flame retardant containing compounds). Due to miniaturisation these compounds replace more and more thermosets, such as phenolics, melamines, diallyl phthalate, polyesters. This is notably the case in switch gears due to a reduction in wall thickness and an incorporation of multi-components into one compact part.

The most demanding requirement in this segment is to have flame-resistance and a high CTI. This aspect is better served by PA66-GF-FR than by PBT-GF-FR (see Table 8).

The dielectric strength of PA66-GF is sufficient for usage in these applications, regardless of temperature and moisture content up to a voltage of 500 V (ac). An indication of the latter can be obtained from Appendix 1, Figure 10. At 80°C and a moisture content of 2.5%, a dielectric strength level of 5 kV/mm is still maintained, allowing a wall thickness of 0.1 mm in case a voltage of 500 V is applied.

Due to the fact that PA66-GF-(FR) compounds are used instead of neat PA66, the dimensional stability is sufficient (roughly speaking, 1% moisture results in 0.1 vol% change). The elongation at break for PA66-GF is large enough to enable snap fits (otherwise impact modified grades are needed at the expense of strength and modulus) [24]. In automotive under the bonnet applications the chemical resistance of PA is an advantage to use it in e.g. power connectors.

The high CTI and dielectric strength of PA66-GF-(FR) makes it very suitable for its usage in bobbins, coil formers and relays, having high insulating requirements. Other requirements are excellent creep, high stiffness, high toughness. The CTI of PBT-FR is too low to be generally applied in bobbins and coil foil formers.

PA46 (Stanyl, ex. DSM) profiles itself in this market segment as a cost effective solution in cases where an improved heat performance, higher mechanical strength and high precision mouldings (including lower warpage) are required [25].

PA11 or PA12 are less moisture sensitive than PA66. PA11 or PA12 are therefore applied in electrical assemblies used in high humidity applications. Whereas PA66 shows a sharp increase in relative permittivity above 65% relative humidity, PA11 only marginal increases [19], indicating better insulating properties.

The main drive in these type of applications is to identify flame retardant grades based on halogen and red phosphorous FR systems. From literature and contacts with major companies in the electro-technical industry, the following set of general material requirements was deduced which needed to be fulfilled in order to introduce new material in these class of applications [22,26,27,28]:

- no halogen or red phosphorous containing FR system,
- UL 94, V-0 at 1.6 mm [27] or V-1 at 0.8 mm [28],
- glow wire temperature (IEC 695-2-1): 960°C
- CTI > 400 V,
- HDT/A > 200°C,
- CUT (20,000 h) ≥ 120°C,
- E-modulus: 7 - 8 GPa,
- elongation at break > 2.4%.

(A more specific set is given in Appendix 2.)

Additionally requirements can also be made (especially in high voltage applications up to 1000 V (ac) or 3000 V (dc)) [22]:

- dimensional stability, independent of humidity and temperature,
- chemical resistance towards chemicals used in electric assembly,
- to withstand electrolytic corrosion.

Currently no halogen or red phosphorous free PA-GF-FR or PBT-GF-FR grades are commercially available.

6.2   Sensors and Capacitors

Sensors are used for example in automotive electronics and domestic appliances. Their general requirements are [6,26]:

- high relative permittivity (high capacitance), but low dissipation factor to minimise heat built-up,
- extremes of temperatures,
- resistance against humidity and aggressive chemicals,
- high toughness,
- creep resistance.

General requirements for capacitors to be used a.o. in circuit breakers and caps [25]:

- outstanding creep properties at high temperatures,
- good thermal and dimensional stability,
- excellent chemical resistance (especially high temperature caps).

6.3   Electrical Equipment Housings

Housings for electrical equipment are a large and diverse market. It encompasses housings in business machines, audio/video equipment, domestic equipment etc.
Often one classes these type of applications in either the business machines and computer goods sector or the electrical appliances and consumer goods sector [2]. In this section, only housings for equipment with an E/E function will be dealt with.

Requirements

The main requirements for housings with an E/E function are a certain level of temperature resistance, good toughness and good surface quality. This market segment is dominated by amorphous polymers.

Materials

From a price/performance point of view, ABS is very attractive. It has a relatively high impact strength and stiffness, good surface quality, good electrical insulating properties and resistance against a number of aggressive chemicals. Its Vicat softening temperature at 50 N loading and heating rate of 120 K/hr (VST/B 120) falls in the range 90 to 115°C (HDT/A is 70°C). ABS is especially attractive in cases where no flame resistance is required, e.g. in vacuum housings.

If both flame resistance and a higher temperature resistance are demanded polycarbonate/ABS blends (PC + ABS) are used, e.g. in enclosures and cases for personal, lap-top and handhold computers, copiers, printers and point-of-sale terminals. (PC and ABS have shrinkage rates which are very close, i.e. 0.5 and 0.7%.) With FR systems it is possible to obtain UL 94 V-0 up to 1.6 mm. Its VST/B increases to 90 - 130°C (HDT/A is 90°C). The mechanical properties are about 20% higher as that of ABS. Other advantages are a higher heat stability and easier mouldability than PC (high processing stability, high flowability) [2,29].

PC can be used in an even higher temperature range. Its VST/B 120 is 145 - 150°C. Furthermore PC has a high transparency, high toughness, good electrical insulating properties and high light stability. With FR it is even possible to obtain UL 94 V-0 up to 0.8 mm. Further developments of PC in this are concentrated on the development of non-halogenated FR systems and on even more severer FR requirements i.e. UL 94 5V. Another development is glass reinforced PC. For example PC-GF20 containing non-halogenated FR system (e.g Makrolon 6485 ex. Bayer) which is used in fuse boxes and manifold housings [24].

Shielding

Housings containing electronic parts have to be shielded against electromagnetic waves. Electrical resistive materials like most polymers are normally transmissible for electromagnetic radiation or fields. The requirements for the whole apparatus are written down in national and international rules (e.g. VDE 0871). The necessary shielding against electromagnetic waves in computers is often obtained by armour-plated metal inside, the attachment of a metal layer to the housing by metal vapouring, varnishing with conductive varnish or chemogalvanistic metallising. Another method for EMI shielding is to use compounds containing metal fibres [24].

6.4   Alternators and Electrical Motors

This section briefly outlines some of the applications with both a mechanical and electrical function i.e. alternators and electrical motors (electrical tools). A complete classification of these applications will almost be a classification of the automotive or domestic appliances sectors, taking into account all requirements attached to the non-electrical functions involved. Such classification goes beyond the scope of this study. Examples of electrical motor parts are coil formers, end laminates and brush holders. Due to the heat generated during running, a high temperature resistance is required.

In electrical tool casings, PA-GF is traditionally used. Its moisture sensitivity remains however a disadvantage. New PA types are developed by BASF and Bayer which have a reduced moisture sensitivity, viz. an approximately 30% lower water absorption. For example, Ultramid T, ex. BASF (PA6/6 T i.e. partial aromatic transparent PA, polymerised from caprolactam, hexamethylenediamine and terephthalic acid; T_m = 295°C) PA6/6 T is also applied in electrical assemblies [30].

6.5   Lighting

Examples of ETP's used in lighting applications are parts of housings, reflectors and lamp sockets in domestic and commercial installations. The requirements rely on the type of bulb and power used and the environment i.e. outdoor or indoor lighting, domestic or industrial lightning.

Requirements

Nonetheless some general requirement for lighting applications can be given [31]:

-        sufficient level of heat resistance for extended periods of time (heat resistance in ball pressure test of at least 125°C),
-        colour retention at high temperatures,
-        mechanical strength,
-        UV resistance,
-        moisture proof for outdoor usage,
-        flame-resistance, in case of emergency light fittings,
-        chemical resistance for usage outdoor or in industrial environment,
-        surface resistance $\leq 10^9\ \Omega$ (at 23°C/50% R.H.) for explosion-proof light fittings (VDE 0170/0170).

Materials

PBT (and also PET) is very suitable in lighting applications. Compared to PA it has a superior colour retention at elevated temperatures, a high long term heat resistance, low moisture sensitivity. Furthermore, PBT has a good light stability. PC is also used in lighting, especially in strip lighting. With respect to polyesters, PC is more flexible and dimensional stable. The long term heat stability of polyesters is however better. A copolycarbonate, Apec HT, with an improved heat stability has been developed by Bayer (VST/B 120: 160 - 205°C) [32]. PPS-GF is used in halogen lamp sockets due to the high temperatures involved [33].

7   STRENGTH AND WEAKNESSES OF ENGINEERING THERMOPLASTICS IN ELECTRICAL AND ELECTRONIC APPLICATIONS

Listing the pro's and contra's of the different ETP's, concerning the most important properties required in E/E applications, the following overview is obtained. The ETP data mentioned in this section are stemming from suppliers data sheets for commercial grades (Appendix 3).

As mentioned in this report, flame-resistance and heat ageing resistance are crucial requirements for the usage of ETP's in E/E applications. Studies to identify effective additives to meet both requirements are still in hand. It is therefore premature (c.q. impossible) to estimate fully the edge of CARILON polymers in this sector.

Electrical (insulating) properties

The major electrical properties for PA66, PBT and PC compounds are given in Tables 8 and 9. Most ETP's are sufficient insulators. High relative permittivity and dissipation factor may not be ideal for high frequency applications. For PA having a high moisture content, this is a disadvantage. The high volume resistivity of PBT can be an advantage for applying it in connectors. Ultimate electric properties like the CTI (Table 9) are especially important in electrotechnical c.q. high voltage applications. The highest CTI is obtained with PA. The CTI of PC is low.

FR systems can have its repercussions on the CTI. PA-FR possesses the highest CTI (and a high dielectric strength) whereas the CTI of PBT-FR is too low for a number of such applications.

With respect to the electrical properties of CARILON polymer, it is an advantage that the dissipation factor is not so high as that of conditioned PA66, which has the risk to melt at high voltage stress and/or high frequencies. Also CARILON polymer, neat as well as glass fibre reinforced, benefits from a high tracking index, as is the case with PA66 grades.

Flame resistance

The majority of E/E applications requires a certain level of flame-resistance. The flame resistance of different ETP's and their compounds is given in Table 9. The best intrinsic flame resistance, i.e. UL 94 V-2, is obtained with PC, PA6 and PA66. All other ETP's, including CARILON polymer, possess a poorer flame resistance, i.e. they do not pass this vertical flammability test. They only pass the horizontal flammability test UL 94 HB. (Note, PA6-GF or PA66-GF are also UL 94 HB.) HB classified materials are in general not recommended for electrical applications except for mechanical or decorative purposes.

To fulfil UL 94 V-0 requirements, FR components, in relatively large quantities, need to be added. Examples of FR systems for PA, PBT, PC and CARILON polymer are given in Table 10. These systems can have a large influence on all properties (electrical, mechanical, thermal) as well as on the melt processing (see Tables 8, 9, 11 and 13).

The fact that no suitable FR systems exist for POM (at least which will maintain mechanical properties of the same order of magnitude), explains its absence in this market sector. (The flame-resistance of ABS is also limited. ABS-FR compounds exist but are price/performance-wise less attractive than for example (PC + ABS) blends.)

Results of the FR development programme at KSLA showed that, as in PA, red phosphorous is an effective FR in CARILON polymer, neat as well as glass fibre reinforced.

The CTI is thereby hardly effected (Table 10). More interestingly however is the identification of halogen and red phosphorous free FR systems. They give sufficient flame-resistance in order to fulfil UL 94 V-0 up to 1.6 mm and probably even 0.8 mm. The CTI of CARILON-FR compound is thereby hardly effected [10]. The development of CARILON-GF-FR compound on the basis of a.c. magnesium hydroxide FR system is in-hand. Evidence is available that magnesium hydroxide is significantly more effective in CARILON polymer than in PA66, resulting in a set of mechanical properties which may meet the central requirements for electrical assemblies as put by major electrical companies (see section 6.2). Such a CARILON-GF-FR compound has a clear advantage above PA66 and PBT.

Temperature resistance

Short term high temperature resistance is required for the assembly of E/E devices, particular to withstand soldering. The heat generated during continuous use of the E/E devices governs the requirement of a high CUT.

The best temperature resistance is obtained with the so-called "high performance polymers", like PEI, PES, PSU, PPS-GF, PEEK, PEK and LCP's. They are defined as having a HDT/A above 150°C, without the use of reinforcements (PPS-GF is included in this class since it is only supplied as glass reinforced compound). Furthermore they are characterised by a high Continuous Use Temperature (Table 11). All polymers mentioned in Table 11 possess a CUT of 170°C and higher. Besides this, they often possess a high intrinsic flame resistance (UL 94 V-0), high level of mechanical properties, high dimensional stability, high flow, good chemical resistance, etc [33]. With this level of heat performance, reflow soldering and service temperatures requirements for electronic applications are easily met by this class of polymers.

The CUT as given on the so-called "UL yellow card" [34], the relative temperature index (UL 746B), and the HDT/A and VST/B are given in Table 12 for PA66, PBT and PC and their corresponding glass fibre reinforced and/or flame retardant grades.

The softening temperature of PC, like that of POM (VST/B 50 = 150°C), is too low to withstand conventional soldering techniques (Table 7). Having a softening temperature in the range of PBT, one can expect CARILON polymer to withstand the conditions for conventional soldering.

With the exception of highly filled PA66, the major players in the E/E sector, PBT, PC and PA6 can not withstand reflow soldering. The melt temperature of CARILON EP polymer (Tm = 220°C) is also too low to undergo VPS and IR soldering. One can only expect that high filled CARILON E polymer (Tm = 256°C) is resistant to reflow soldering.

From the polymers in Table 12, PBT grades possess the best long term heat performance, followed by PC and heat stabilised PA66 grades. The CUT as based on tensile yield strength for CARILON polymer (85°C) is however still below the level of heat stabilised PA66. One is therefore dependent on the development of additives to improve the heat ageing behaviour of CARILON polymer. The CUT of 30 wt% glass fibre reinforced CARILON compound (120°C) approaches that of PA66-GF30.

The gap between CUT of "high performance polymers" and the highest CUT obtained with ETP's (140°C for PBT) is not fulfilled by CARILON polymers. If CARILON-GF-FR, due to the incorporation of mineral fillers as FR system, at least improves the CUT to a value of 140°C, it has an advantage over PA66-GF-FR compounds.

Mechanical properties

A brief summary of the major mechanical properties at 23°C of PA66, PBT and PC and their corresponding glass fibre reinforced and/or flame retardant grades is given in Table 13.

The highest tensile strength and modulus is obtained with dry PA66. On the other hand, the tensile strength of CARILON polymer, conditioned PA66, PBT and PC fall in the same ball park. At room temperature, the modulus of PBT and PC are higher than that of either conditioned PA66 or CARILON polymer. In PC-GF, the glass fibres do not contribute much to the tensile strength.

The highest toughness (notched Izod) is obtained with PC. The impact performance of CARILON polymer in dart impact even at low temperatures (e.g. -30°C) is almost comparable to that of PC. (In this respect CARILON polymer could be applied in electrical parts having large surfaces at low temperatures where a high CTI is required.) The notched Izod impact is comparable to conditioned PA66. One must however have a good control over the moisture content to maintain this level of impact performance. Something which is difficult in environments having changing temperature and humidity. PBT shows a poor toughness.

CARILON polymer, independent of the moisture content, shows the highest elongation at yield, resulting in a high level of resilience [36]. Only conditioned PA66 can meet this. Resilience is important with respect to the snappability necessarily in a.o. connectors. An indication of the maximum applicable strain in snapfits is given in Table 14 [36].

Both in conditioned PA66 and PBT grades, FR systems cause a decrease in elongation at yield/break, impact performance and slightly in tensile strength. The tensile modulus on the other hand increases.

Dimensional stability

Amorphous polymers like PC are of course preferred with respect to dimensional stability. Moisture sensitive materials like PA are less favourable. Both CARILON polymer and PBT have an advantage in this above PA. However, a large quantity of PA in the E/E sector is consumed as GF reinforced compound, being less sensitivity to moisture. As a result of the miniaturisation trend within the E/E sector, the moisture sensitivity of PA is becoming more problematic.

Chemical resistance

Washing of print boards, components and connectors after soldering needs resistance to cleaning solvent (e.g. trichloroethylene). CARILON polymer, PA and PBT can withstand these solvents, PC not. Not many other specific chemical resistance requirements were found.

With respect to all other ETP competitors in the E/E sector, CARILON polymer has an superior chemical resistance. In this sense it creates new opportunities in applications where these requirements are becoming more severe or traditional materials can be replaced.

8   OUTLOOK

The essential requirements for the major application areas in the E/E sector as deduced from chapters 4 and 5, including competitive materials, are briefly summarised in Table 15. By assessing to which extent CARILON polymer meets these requirements, it is possible to make an estimation of its performance in the different E/E areas. In almost every application a certain level of flame resistance is required. Therefore, the assessment has in fact to be carried out on the basis of FR CARILON compounds. Since the compound development is still in-hand, the performance of CARILON EP polymer in E/E is guesstimated on the basis of neat material data, see Table 16.

With respect to circuit boards and lighting applications, the CUT of CARILON polymer is in general too low to fulfil their requirements. Furthermore, the UV requirements for lighting parts directly exposed to light can be too severe for CARILON polymer. The short term high temperature resistance of CARILON EP polymer to reflow soldering conditions as well as its strength and stiffness are too low to be applied in circuit boards.

In those applications driven by the miniaturisation trend, c.q. high CUT, CARILON polymer will not fulfil the gap in materials between PBT (CUT = 140°C) and the so-called "high performance polymers".

The CUT of CARILON polymer will probably meet the requirements for the other applications areas mentioned in Table 16 but it could still be critical for some of the segments within these areas. Although a number of properties still needs to be determined (creep, electrolytic corrosion), the impression is created that CARILON EP polymer can meet essential requirements for electronic components and connectors and electrical assemblies. To apply CARILON polymer in electrical housings, the UV resistance could be critical. However it will rely completely on the specific requirements per application if CARILON polymer will fulfil the requirements.

The challenge in the electrotechnical sector is to come up with halogen and red phosphorous free FR systems, especially in glass filled compounds. For the major players in this field, PA and PBT, no such systems are currently available (only for PA neat) while for CARILON polymer they have already been identified at KSLA for CARILON polymer.

9   CONCLUSIONS AND FURTHER WORK

*   Based on its general intrinsic properties, CARILON polymer is suitable to be applied in E/E applications. In electrical terms, especially its high Comparative Tracking Index (CTI) is an advantage.

*   The E/E sector consists of a very diverse range of applications. Each demands its own particular set of requirements. An individual approach, based on tailor made GF/FR compounds is necessary to meet the required levels of flame-resistance, high temperature resistance and/or stiffness.

*   The E/E segments with the highest probability of success for CARILON polymer are listed in Tables 15 and 16. A drive for market introduction of CARILON polymer lays particular in those areas requiring halogen and red phosphorous free FR systems (e.g. electrical assemblies) and not in the areas driven by higher temperature resistance (e.g. electronics).

Compound finishing and evaluation:

*   The amount of effort necessarily to develop this sector is very extensive. For CARILON-GF-FR compounds, it is necessary to assess all important performance requirements as function of the GF and FR content. To explore such ternary systems, experimental design seems an inevitable tool.
        The 26 requirements for a GF/FR compound given in Appendix 2 are of prime importance as guidance for product development in this segment.

*   Emphasis should be on obtaining an "UL yellow card" for the optimised CARILON-GF-FR grade. The grade should be balanced against other competitive grades in terms of melt processing (including moulding behaviour), heat performance, flame resistance, electrical and mechanical properties etc.

End product testing:

*   Many other performance requirements also need to be established for CARILON polymer and its compounds, e.g. electrolytic corrosion, environmental stress cracking, creep resistance as function of temperature, resistance against cleaning compounds (a.o. trichloroethylene).

*   Last but not least, many properties need to be evaluated on end product. This requires a close and intense cooperation with leading part-manufacturers, e.g. Siemens (D), Schneider (F).

Louvain-la-Neuve, December 1993.

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E/E market segment	Forecast growth per annum %
Components	8
Consumer electronics	3
Light engineering	1.5
Domestic appliances	1.5
Medical electrology	3
Electrical tools	3
Data processing	9
Processing machine and control technology	6
Telecommunication engineering	8
Distribution of electricity	1.5
Production and conversion of electric energy	2
Other	3

Table 1: Forecast growth per annum for different segments in the E/E market
in the Western part of Germany between 1990 and 1995 [3]

Material	Volume tonnes	Part of material's total consumption as ETP %	Part of materials consumption in the E/E sector %	Average annual growth in the E/E sector %
PA66	45,000	28	27.3	9.0
PA6	42,000	26.1	25.4	1.0
PA11/12	2,000	10	1.2	8.5
PBT	10,000	38.2	6.1	11.2
PET	4,800	10	2.9	4.6
POM	5,000	5	3.0	1.9
PC	21,000	15	12.7	4.4
ABS	18,000	3.6	10.9	3.2
PPO	12,000	24	7.3	4.6
Polyarylates	110	24.4	0.07	7.8
PPS	1000	50	0.6	11.8
PEI	200	40	0.1	8.5
PSU/PES	850	40.5	0.5	9.7
PEEK/PEK	25	18.5	0.02	9.9
Polyamide-imide	200	6.7	0.00	8.4
LCP	50	50	0.03	19.1
Fluorpolymers	3,100	20	1.9	2.5
PP	-	-	-	-
Total	165,135		100	average: 5.4

Table 2: Share of ETP's in E/E sector for the European market in 1989 [2]

Mechanical term	Electrical term
Force (N)	Voltage (V)
Stress (N/m²)	Stress (V/m)
Strain (m/m)	Current density (A/m²)
Stiffness (N/m)	Resistance (Ω)
Modulus (N/m²)	Volume resistivity (Ω.m)
Dynamic modulus (N/m²)	Specific impedance (Ω.m) (and permittivity)
Strength (N/m²)	Dielectric strength (V/m)
Mechanical losses	Dielectric losses
(or loss factor, tan δ)	(or loss factor, tan δ)
Stress concentrations	Stress concentrations
Environmental stress cracking	Tracking and corona discharges
Crazing	Treeing
Impact strength	Impulse breakdown voltage

Table 3: Analogy between mechanical properties and electrical properties [4]

Electrical properties		ASTM method	
Relative permittivity		D 150	
@ 1 kHz			5.5
@ 10 kHz			5.4
@ 100 kHz			5.2
Dissipation factor		D 150	
@ 1 kHz			0.14
@ 10 kHz			0.18
@ 100 kHz			0.30
Volume resistivity	10^{15} Ω.cm	D 257	0.034
- after 96 hr @ 35°C/90% R.H.	10^{15} Ω.cm		0.081
Surface resistivity	10^{13} Ω	D 257	0.37
Dielectric strength, short term		D 149	
@ 3.2 mm thickness	kV/mm		12
@ 1.6 mm thickness	kV/mm		18
- after 96 hr @ 35°C/90% R.H.	kV/mm		30
@ 0.8 mm thickness	kV/mm		30
Arc resistance	s	D 495	130
CTI	V	D 3638	600

Table 4: Electrical properties of CARILON polymer determined by Hoechst Celanese

Electrical properties	CARILON [a] Ref.11 [e]	PA66 [b] Ref.11 [e]	PA66 [b] Ref.12. [fg]	PBT [c] Ref.11 [e]	POM [d] Ref.11	POM [d] Ref.12 [f]
Relative permittivity						
@ 50 Hz	-	-	3.8[g]	-	-	3.8
@ 1 kHz	7.1	4.5	3.5[g]	4.2	4.6	3.8
@ 10 kHz	7.0	4.5	-	4.3	4.6	-
@ 100 kHz	6.9	4.3	-	4.3	4.6	-
@ 1 MHz	6.5	4.2	3.2[g]/5.0[h]	4.2	4.6	3.8
@ 10 MHz	6.2	4.2	-	4.2	4.7	-
Dissipation factor						
@ 50 Hz	-	-	0.005[g]	-	-	0.0010
@ 100 kHz	0.024	0.018	0.013[g]	0.009	-	0.0015
@ 1 MHz	0.047	0.017	0.025[g]/0.2[h]	0.016	0.004	0.0025
@ 10 MHz	0.066	0.015	-	0.015	0.016	-
Volume resistivity10 [15]Ω.cm	0.12	5.4	1[g]/0.001[h]	5.4	0.37	1
Surface resistivity 10 [13]Ω	510	140	1[g]/0.001[h]	160	340	1

a = DP501 13-MX500 Lot 04NMB00001
b = Ultramid A3W, ex. BASF
c = Duranex 2002, ex. Polyplastics
d = Ultraform N2320, ex. BASF
e = test method unknown
f = measured according to test methods predescribed in CAMPUS (see Appendix 1)
g = dry as moulded
h = conditioned to 50% R.H. at 23°C

Table 5: Electrical properties of CARILON polymer and competing ETP's, determined by MYKK [8]

Electrical properties	CARILON-GF30[a] Ref.11[d]	PA66-GF30[b]		PBT-GF30[c] Ref.11[d]
		Ref.11[d]	Ref.12,13[e]	
Relative permittivity				
@ 50 Hz	-	-	3.9[f]	-
@ 1 kHz	5.7	5.0	3.8[f]	4.8
@ 10 kHz	5.6	4.9	-	4.8
@ 100 kHz	5.5	4.8	-	4.7
@ 1 MHz	5.4	4.7	3.5[f]/5.5[g]	4.6
@ 10 MHz	5.2	4.7	-	4.6
Dissipation factor				
@ 50 Hz	-	-	0.007[f]	-
@ 100 kHz	0.013	0.018	0.009[f]	0.008
@ 1 MHz	0.028	0.016	0.014[f]/0.3[g]	0.014
@ 10 MHz	0.043	0.014	-	0.013
Volume resistivity 10^{15} Ω.cm	0.12	1.2	1[f]/0.001[g]	81
Surface resistivity 10^{13} Ω	350	630	0.1[f]/0.001[g]	1400

a = PKX100B
b = Ultramid A3WG6, ex. BASF
c = Duranex 3300, ex. Polyplastics
d = test method unknown
e = measured according to test methods predescribed in CAMPUS (see Appendix 1)
f = dry as moulded
g = conditioned to 50% R.H. at 23°C

Table 6: Electrical properties of 30 wt% glass fibre reinforced CARILON polymer and competing ETP's, determined by MYKK [8]

Polymer	Resistance to 240°C for a few seconds [a]
PA	+
PBT	+
PP	-
PES	+
PSU	+
PEK	+
LCP	+
PE	-
PVC	-
ABS	-
SAN	-
PS	-
POM	-
PC	-

(a) + = no change; - = deformation

Table 7: Resistance to high temperature (240°C for a few seconds) for different ETP's [20]

Material		Relative permittivity IEC 250 @			Dissipation factor IEC 250 @			Volume resistivity IEC 93	Surface resistivity IEC 93	Dielectric strength IEC 243 (K25/P50) (in oil)
		50	10^3	10^6	50	10^3	10^6			
			Hz			Hz 10^{-3}		$10^{16}\Omega$.cm	$10^{13}\,\Omega$	kV/mm
PA66	C	10	-	4	1500	-	300	0.001	10	30
	D	3.8	3.5	3.4	30	-	70	>1	100	30
PA66-FR	C	8	-	4	200	-	55	0.1	10	25
	D	4	-	4	8	-	15	>1	100	40
PA66-GF30	C	9	-	5	130	-	70	0.01	1	35
	D	4	-	4	8	-	15	>1	100	40
PA66-GF25-FR	C	-	-	5	-	-	100	0.001	0.01	-
	D	-	-	4	-	-	20	1	10	-
PBT		3.8	3.2	3.2	3	2	19	10	1000	30
PBT-FR		3.4	3.4	3.2	1	2	15	10	1	28
PBT-GF30		3.8	3.7	3.5	3	3	18	10	>100	34
PBT-GF30-FR		4.0	3.9	3.9	5	3	16	10	1000	28
PC		3	3	2.9	0.9	1	10	10	100	30
PC-FR		3	3	3	0.9	1	9	10	100	30
PC-GF30		3.3	3.3	3.3	0.9	1	9	10	10	30
PC-GF20-FR		3.2	3.2	3.2	0.9	1	8	10	10	30

C: conditioned to 23°C/50% RH
D: dry as-moulded

Table 8: Electrical properties of different ETP compounds [9,39,40,41]

Material	Flame-resistance UL 94 (@ 1.6 mm)	Comparative tracking index IEC 112	
		CTI	CTI(M)
ABS	HB	600	250
ABS-FR	V0	325	
PA6	V-2	600	600
PA6-FR	V0	550	
PA6-GF30	HB	600	
PA66	V-2	600	575
PA66-FR	V0	550	500
PA66-GF30	HB	600	400
PA66-GF30-FR	V0	400	
PBT	HB	600	350
PBT-FR	V0	375	100
PBT-GF30	HB	350	125
PBT-GF30-FR	V0	150	100
PC	V-2	275	100
PC-FR	V0	200	100
PC-GF30	V-1	175	100
PC-GF20-FR	V0	175	100
POM	HB	600	600
POM-GF25	HB	600	600
CARILON	HB	600	
CARILON-FR	V0	575	
CARILON-GF30	HB	550	
CARILON-GF30-FR	V0		

Table 9: Flame resistance and comparative tracking index of different ETP compounds [20,37,38]

Flame retardant system		Flame-resistance (UL 94) @ 1.6 mm	CTI (IEC 112) V
PA6 and PA66			
Poly-dibromophenylene oxide	17 - 20%	V-0	
Antimony trioxide	4 - 5%		
Chlorinated cycloaliphatic	7 - 10%	V-0	
Antimony trioxide	10 - 12%		
Ethylene-bis-tetrabromophtalimide	7 - 10%	V-0	
Antimony trioxide	4 - 5%		
Red phosphorous	7 - 10%	V-0	600
Red phosphorous	7%	V-0 @ 0.8 mm	400
Glass fibre	35%		
Melamine cyaurate[a]	10%	V-0 @ 0.8 mm	≥ 600
Magnesium hydroxide	55%	V-0	≥ 600
Glass fibre	13%		
Dechlorane	19%	V-0 @ 0.8 mm	250
Antimony trioxide	5%		
Glass fibre	28%		
PBT			
Decabromodiphenyl ether	10 - 12%	V-0	
Antimony trioxide	3 - 4%		
TBBA-carbonate oligomer	15 - 18%	V-0	
Antimonytrioxide	4 - 5%		
Ethylene-bis-tetrabromophthalimide	7 - 10%	V-0	
Antimonony trioxide	3 - 4%		
PC			
Poly-dibromophenylene oxide[b]	3 - 4%	V-0	
Antimony trioxide	1 - 2%		
Ethylene-bis-tetrabromophtalimide[b]	2 - 3%	V-0	
Antimony trioxide	1%		
CARILON			
Red phosphorous	20%	V-0 @ 1 mm	≥ 600
Red phosphorous	7%	V-1 @ 1 mm	≥ 600
Glass fibre	35%		
Magnesium hydroxide	30%	V-0 @ 1 mm	≥ 600
Magnesium Calcium hydrated carbonate	25%	V-0	575

a = unefficient with glass fibres
b = non optical

Table 10: Flame retardant formulations for PA6, PA66, PBT, PC and CARILON [42]

| Material | Relative temperature index UL 746B | | | HDT/A ISO 75 (1.8MPa) | VST/B 50 ISO 306 (50 N) |
	Electrical °C	Without impact °C	With impact °C	°C	°C
PA66	105	85	75	70	230
	105 [a]	110 [a]	95 [a]		
PA66-FR	130	95	90	80	230
PA66-GF30	105	105	75	250	230
	130 [a]	130 [a]	115 [a]		
PA66-GF25-FR	115	130	115	250	250
PBT	140	140	120	60	190
PBT-FR	140	140	130	70	190
PBT-GF30	130	140	130	210	215
PBT-GF30-FR	140	140	130	210	210
PC	125	125	115	130	145
PC-FR	125	125	115	125	145
PC-GF30	125	125	115	135	150
PC-GF20-FR	-	120	105	135	145
CARILON	-	85 [b]	-	90	194
CARILON-GF30	-	125 [b]	-	215	-

a = heat stabilised variant
b = CUT based on maximum tensile strength; not according to UL 746B

Table 11: Heat performance of different ETP compounds [34,38,39,40,41,43]

Material	Relative temperature index UL 746B Without impact °C	HDT/A ISO 75 (1.8MPa) °C
PSU	170	175
PES	180	195
PEI	170	195
PAI	220	275
PPS-GF40	220	265
PAEK	250	150
PEEK	255	160
PEK	260	185

Table 12: Heat performance of different high performance polymers [33]

| Material | | Tensile properties ISO 527 | | | | Izod impact strength ISO 180 | |
		Maximum strength MPa	Elongation at yield %	Elongation at break %	Modulus GPa	1A kJ/m²	4A kJ/m²
PA66	C	60 ᵃ	20	>200	1.7	15	25
	D	95 ᵃ	5	20	3.6	5	4
PA66-FR	C	50 ᵃ	20	>50	1.8	9	-
	D	90 ᵃ	4	6	3.8	6	6
PA66-GF30	C	125		5	6.5	16	-
	D	185		3	9.3	12	11
PA66-GF25-FR	C	120		4	6.5	12	-
	D	160		4	9.0	8	10
PBT		57 ᵃ	3.7	20	2.6	5	-
PBT-FR		60 ᵃ	3	10	3.2	6	-
PBT-GF30		150		3	10.5	9	-
PBT-GF30-FR		135		2	11.5	8	-
PC		63 ᵃ	6	120	2.4	-	90
PC-FR		63 ᵃ	6	100	2.4	-	64
PC-GF30		70		3.5	5.8	-	8
PC-GF20-FR		100		3.5	6.0	-	8
CARILON		60 ᵃ	25	350	1.6	15	-
CARILON-GF30		130		2.5	7	8	-
CARILON-FR		56	8	10	2.6	-	-
CARILON-GF20-FR							

a = tensile strength at yield
C = conditioned at 23°C/50% R.H.
D = dry as moulded

Table 13: Mechanical properties of different ETP's at 23°C [38,39,40,41,43]

Material		Indication of the maximum applicable strain in snap fits %
PA	C	6.0
	D	4.0
POM		6.0
PBT		5.0
PC		4.0
PC/ABS		3.0
ABS		2.5
PA-GF30	C	2.0
	D	1.5
PBT-GF30		1.5
PC-GF30		1.8
ABS-GF30		1.2
PPS-GF45		1.0

C = conditioned at 23°C/50% R.H.
D = dry as moulded

Table 14: Indication of maximum applicable strain in snapfits
for neat and glass fibre reinforced ETP's [36]

Essential requirements in E & E Applications

		Electronic			Electrical				
		PCB	Compon.	Conn.	Switch	Assemblies Conn.	Bobbin	Housing	Lighting
Electrical properties	ϵ_r, tg δ	L							
	R								
	E_a		H		H	H	H		
	CTI		H		H	H	H		
Flame resistance,	UL 94	←-------------- all V2/V0 ----------------→						HB/V0	V2/V0
Temperature resistance,	CUT, °C	>150	>90	>90	>90	>90	>90	>70	>130
	HDT/A, °C	>150							
	convent. soldering		+	+	+	+	+		
	reflow soldering	+							
Mechanical properties	strength	XH			H		H	M/H	H
	stiffness	XH			H		H		H
	impact		H						
	creep						H		
Dimensional stability,		H			H	H			
	moisture absorption.								L
	thermal expansion			L					
Chemical resistance		H	H	H	H		H		
	solvent resistance		+	+	+				
	electrolytic corrosion								
	UV resistance							H	H
	discolouration								L
	surface quality							H	
Competitors		PEI PES	PA PBT	PA, PC PBT	PA PBT	PA PBT	PA (PC)	ABS, PC ABS/PC	PBT, PC PET

L = low;   M = Medium;   H = High;   XH = Extra High

Table 15: Summary of essential requirements for major applications in the E/E sector, including competitive materials.

Estimated performance CARILON EP against Engineering Thermoplastics

		Electronic			Electrical				
		PCB	Compon.	Conn.	Assemblies			Housing	Lighting
					Switch	Conn.	Bobbin		
Electrical properties	ϵ_r, tg δ	? -							
	R								
	E_α		=		=	=	=		
	CTI		+		+	+	+		
Flame resistance	UL 94				all =				
Temperature resistance	CUT (°C)	-	? =	? =	? =	? =	? =	? =	-
	HDT/A (°C)	-							
	convent. soldering		=	=	=	=	=		
	reflow soldering	-							
Mechanical properties	strength	-			+		+	+	+
	stiffness	-			+		+		+
	impact		+						
	creep						? =		
Dimensional stability		? =			+	+			
	moisture absorption								+
	thermal expansion			? =					
Chemical resistance								+	
	solvent resistance	+	+	+	+				
	electrolytic corrosion		? =	? =	? =				
UV resistance								? -	? -
	discolouration								? -
	surface quality							? =	
Competitors		PEI PES	PA PBT	PA, PC PBT	PA PBT	PA PBT	PA (PC)	ABS, PC ABS/PC	PBT, PC PET

+ out-performs competition = meets requirements ? needs to be measured - does or will not meet requirements

Table 16: Guestimateds performance of CARILON polymer for major applications in the E/E sector

APPENDIX 1

Electrical properties

The major electrical properties and their meaning in E/E applications are separately discussed below. Comments are added as to how these properties can be influenced and need to be tested following the European plastic data bank system CAMPUS (Computer Aided Material Preselection with Uniform Standards).

1   Dielectric properties

The **relative permittivity or dielectric constant** is the relative measure of dielectric constant (ϵ_r) i.e. the dielectric constant of a material (ϵ) compared to that of a vacuum (ϵ_0; 0.08854 pF/cm). Hence, it describes the ability of a material to store charge. It is a measure of a material's ineffectiveness to dissipate electrical energy and so generating heat [5].

The lower the relative permittivity, the better the performance as an insulator. With respect to electronic applications, the relative permittivity determines:

- the amount of energy which is stored in a material which therefore is lost from the electronic signal,
- the transmission speed of an electronic signal, i.e. the higher the permittivity, the lower the signal speed.

The **dissipation factor or loss tangent** (tan δ) can be considered as the ratio of the dissipated energy and the recovered energy. A low dissipation factor is important for insulators in high frequency applications.

The importance of the dielectric properties, especially in the area of capacitor construction, cable industry and high frequency engineering, can be seen from its relation ship with the loss power [44]:

$$P = 2\pi.\omega.E^2.C.\epsilon_r.\tan \delta \qquad\qquad [1]$$

P = loss power, W
ω = frequency, Hz
E = field strength or voltage between electrodes, V/cm
C = material capacitance
ϵ_r = relative permittivity
tan δ = dissipation factor

Within the CAMPUS plastics data bank, dielectric properties are measured at a frequency of 50 Hz and 1 MHz according to IEC 250 (test specimen geometry: plaque, 1 mm thick). Similar test methods are VDE 0303 T4 (DIN 53483) or ASTM D 150.

<u>Remarks</u>

To reduce the heat generated by an electric current, especially in high frequency applications it is important to have a low value for the product $\epsilon_r.\tan \delta$ i.e. the loss index. On the other hand, a high loss index is needed for heating a material in a dielectricum (viz.in high frequency welding).

Appendix 1

ϵ_r and tan δ are intrinsic material properties. They are often measured as function of T and ω. Apolar materials (e.g. PE, PP, PTFE) have a small tan δ, showing hardly any dependence on T and ω. At frequencies in the range of 50 Hz, polar materials (high tan δ with high T and ω dependency) can also be used. Additives influence the tan δ of a material. The incorporation of glass fibres will lower the tan δ due to its non-polarity.

Examples of the T and ω dependency for PA66, PBT and PC as well as 33 wt% glass fibre reinforced PA66 (PA66-GF33), PBT-GF30 and flame retardant PBT-GF30 (PBT-GF30-FR) are given in Figures 1 to 6.

Heating failure

The effect of a high tan δ, can be illustrated in the case of nylons where narrow channels are melted in a test specimen at high temperatures and frequencies.

Current which is drawn over an insulator in a direct current (dc) field is related to the volume resistance by Ohm's law. In an alternating current (ac) field, it is related to the impedance of the device. It can be represented by the in parallel connection of a capacitance and resistance (yielding a lower value than the dc volume resistance). Current flow through the capacitance represents the energy stored, the flow through the resistance the heat generated. The heat generated due to losses in the dielectric is given by [7]:

$$P = 5.556 \times 10^{-13}.\omega.E^2.V.\epsilon_r.\tan\delta \qquad [2]$$

P = loss power, W
ω = frequency, Hz
E = voltage gradient, V/cm
V = volume insulator, cm^3
ϵ_r = relative permittivity
tan δ = dissipation factor

Assuming no loss of heat to the surrounding, the temperature rise in one minute of applied voltage can be described by [5]:

$$\Delta T = 1.235 \times 10^{-7} \ E^2.\epsilon_r.\tan\delta/S.C_v \qquad [3]$$

S = specific gravity, g/cm^3
C_v = specific heat at constant volume, J/kg.K

2　　Resistivity

Volume resistivity is the intrinsic resistance to the passage of electric current through the bulk of a material. It is hardly effected by wall thickness and frequency but it is strongly dependent on temperature, as is illustrated for PA66 and PA66-GF33 in Figure 7. Moisture sensitive materials like PA66 show also a strong dependency on the water content (Figure 8).

Surface resistivity is the resistance to the passage of an electric current along the surface. Surface leakage paths due to the absorption of moisture makes this type of resistivity distinct from volume resistivity. Opposite to volume resistivity, it is impossible to calculate the intrinsic surface resistivity since one always incorporates a part of the inner volume.

Appendix 1

Surface resistivity is very sensitive to surface contamination and environmental conditions. It is therefore a critical property to determine. It is only useful for general comparison of materials and not for example as an input in the design of an insulator.

Test method IEC 93 or DIN VDE 0303 T3 (DIN 53482) are used in the CAMPUS data bank for both surface and volume resistivity (test specimen geometry: plaque, 1 mm thick). IEC 167 also covers resistivity measurements, whereas IEC 345 describes resistivity tests at elevated temperatures. The American resistivity measurements are based on ASTM D 257.

Remarks

In Anglo-Saxon data sheets, one means with "surface resistivity" the specific surface resistivity, being independent of the electrode geometry (unit: Ω). In German data sheets, the surface resistance (R_{OA}) is sometimes used (unit: Ω.cm). If determined according to DIN VDE 0303 T3 (electrodes set A), R_{OA} can be converted into the specific surface resistivity by multiplying it with a factor 10. CAMPUS version 2 (multi-point data) uses the specific surface resistivity [45].

Resistivity values in CAMPUS are only given up to a value of 10^{16} Ω or Ω.cm. Higher values are denoted as $> 10^{16}$ Ω or Ω.cm [45].

3   **Dielectric strength**

The dielectric strength (E_d) is a measure of the electrical breakdown resistance under an applied voltage. It is defined as the ratio of breakdown voltage and the distance between the electrodes.

Dielectric strength is not a material constant but relies strongly on the electrode, specimen geometry and medium used. Comparing the electric breakdown resistance of different materials has therefore only a limited value (material inspection, quality control). The voltage stress (or voltage gradient, i.e. the applied voltage divided by the product thickness) at which an electrical device works is much lower, mostly 2 - 20% of the dielectric strength [7].

In CAMPUS, the dielectric strength is measured according to IEC 243-1 or DIN VDE 0303 T21 (test specimen geometry: plaque, 1 mm thick). In order to prevent flash-overs, the test is carried out in transformer oil (specified in IEC 296). In CAMPUS version 1 (single point data) the dielectric strength is measured using a pair of electrodes consisting of coaxial cylinders having a diameter of 25 and 75 mm (P25/P75). The set of electrodes prescribed by CAMPUS version 2 is neither given in IEC 243-1 (1988) nor in VDE DIN 0303 T2 (1987, draft). It stems from DIN 53481 / VDE 0303 T2 (1974, withdrawn), being a 25 mm diameter ball and a 50 mm diameter cylinder (K20/P50) [45]. Electrode pair P25/P75 is also one of the electrode pairs prescribed in ASTM D 149.

Appendix 1

Remarks

An increase in specimen thickness or area will decrease the dielectric strength since the chances on finding a weak spot are higher in a larger volume of material [16]. An example of the thickness dependency for a.o. PC and POM is given in Figure 9. This Figure also demonstrated that dielectric strength values higher than 100 kV/mm as sometimes are given in data sheets for 1 mm thick plaques (e.g. BASF) do not stem from such plaques but from films (thickness of approximately 0.2 mm).

In general, an increase in temperature will lower the dielectric strength. A clear example is that of PA, viz. the temperature dependency of the dielectric strength of PA66-GF30 as given in Figure 10. PBT hardly shows such a dependency (Figure 11).

In an AC field, the dielectric strength decreases with increasing frequency as a result of the rise in temperature caused by the increase in dielectric loss due to the increase in frequency.

The dielectric strength relates also strongly to the specimen environment. Oil immersion, as in transformers, increases the dielectric strength due to the increase in voltage at which ionized gases are in contact with the insulation surface. The voltage stress in oil decreases due to the connection in series of the edge of the electrodes, the solid insulation and the oil. (The voltage stress is about half of that in air since the ratio between the dielectric constant in oil to air is 2:1.) [7]

The long term dielectric behaviour, very important in an insulator, behaves differently as in short term measurements (see Figure 12). From 1 μs till 1 s, the dielectric strength is almost constant. For materials having a good electric conductivity or a high dielectric loss in an AC field, exposure to longer periods of time leads to heat breakdown. This is a result of the decrease in dielectric strength due to the rise in temperature. Prolonged exposure, especially for materials which show no heat breakdown (like PE), will result in electrical failure [7].

This type of failure is caused by corona, or partial discharges, attacking the surface of the insulation. This occurs seldom directly beneath the electrode, but away from the edge. It occurs along a growing path of minimum voltage breakdown yielding tree or dendrite. This tree grows under continuing voltage stress till it reaches the opposite specimen. (The breakdown path is related to Paschen's law, describing the relationship between breakdown voltage in air or gas and electrode spacing and air pressure.) [7,46]

The lower the applied voltage level compared to the short time dielectric strength, the longer it can last. On the basis of such measurements a voltage endurance curve can be determined (Figure 13). With time this voltage becomes constant. The corresponding voltage stress represents the maximum operating stress at which the insulation should, in the absence of other deteriorating effects, last forever (to be used in electrical design).

Appendix 1

4   Tracking resistance

Tracking is the progressive formation of a conductive path across the surface of an insulator by surface discharges as a result of moisture or dirt deposition.

A good insulator recovers as a result of a clean up of the surface due to the heating effect of the leakage current. A permanent change (electrical breakdown) arises when the surface dries out and narrow 'dry bands' are formed. Most of the voltage drops over the high resistance of the narrow bands, causing sparks (scintillations) which may char the polymer. In this way a conductive track develops along the surface, ultimately resulting in flash-overs (setting sometimes fire to the polymer) [46].

The low-voltage tracking sensitivity of a material in a short period in time is expressed by the **Comparative Tracking Index** (CTI). It indicates the voltage at which a material continues to resist tracking when it is contaminated and under electrical stress. Failure is defined if at an applied voltage a current of at least 0.5 A flows for a minimum of 2 s in a conductive path between two electrodes on the material surface within the addition of 50 drops of a 0.1 wt% ammonium chloride solution (resistivity is 395 Ω.cm). For applications which are expected to be in contact with special aggressive polluting environments, the CTI(M) test is applied. It is similar to the CTI test except that the conditions are more severe, e.g. a solution of 0.1 wt% ammonium chloride and 0.5 wt% sodium salt of an alkyl naphthalene sulphonic acid (resistivity is 198 Ω.cm) [37].

Within the CAMPUS data bank, the CTI is determined according to IEC 112. Similar methods are VDE 0303 T1 or ASTM D 3638. In literature, one sometimes encounters also a tracking index notated as KA, KB and KC. These are based on the withdrawn test method DIN 53480 [37].

Remarks

The significance of the test voltage and its relationship with the practical use voltage has not yet been established. The CTI provides a comparison of insulating materials under wet and contaminated conditions. It should not be regarded as a design voltage below which it is safe to operate [47].

In general, the CTI is negatively effected by additives. Especially in the case of PBT, the addition of flame retardant (FR) systems decreases the CTI very strongly [22]. Typical CTI values of PA6, PA66, PBT and PC and their corresponding glass fibre reinforced and/or flame retardant grades are give in Table 8.

Test method IEC 112 is designed for materials having a poor tracking index. Above 600 V flashovers tend to occur, making the end-point of the test increasingly difficult to define [47]. For evaluating tracking and erosion resistance of materials under severe ambient conditions (high voltage-low current discharges), IEC 587 (inclined plane test) should be used. ASTM D 2303 is a similar and more closely defined test; its procedures are however markedly different [47].

Measuring the arc resistance deals with surface destruction by arcs instead of electrical discharges as is the case with tracking. Arc resistance is measured according to ASTM D 495. It is expressed as the number of seconds that a material resists the formation of a surface conductive path when subjected to an intermittently occuring are of high voltage, low current characteristics [34]. It is not often used in European data sheets.

Appendix 1

5   Electrostatic behaviour

Electrostatic charging is generated by touching and subsequent separation of surfaces. The value of the surface resistivity, as a measure of surface discharging, already gives an indication of the electrostatic behaviour. Electrostatic charging of the surface is obtained above 10^{14} Ω. Below 10^{10} Ω, the charging is very poor. Most thermoplastics, in dry condition, posses a value of 10^{12} Ω. Only moisture sensitive materials like PA possess lower values.

Remarks

Antistatica (i.e. metal powder or fibres , carbon black, graphite) improve electrostatic discharging. However, quantities of 20 wt% or more are needed, having a negative effect on the processability and mechanical properties. It is possible to improve the surface conductivity by using hydrophillic chemicals. For a short period of time, an external treatment can be successful while for longer periods, compounding of these hydrophilics is a possibility (forming a hydrolytic shield on the surface). Another possibility is a chemical treatment of the surface which results in a conductive surface layer.

By compounding a polymer with metallic or metalliferous fibres, it can become suitable for electromagnetic shielding. In case a polymer is compounded with conductive carbon, it may be used for heat generation purposes (e.g heat retention plates, heater elements for exterior mirrors on motor vehicles, locks on doors and car boots or nozzles for wind screen washers).

Appendix 1
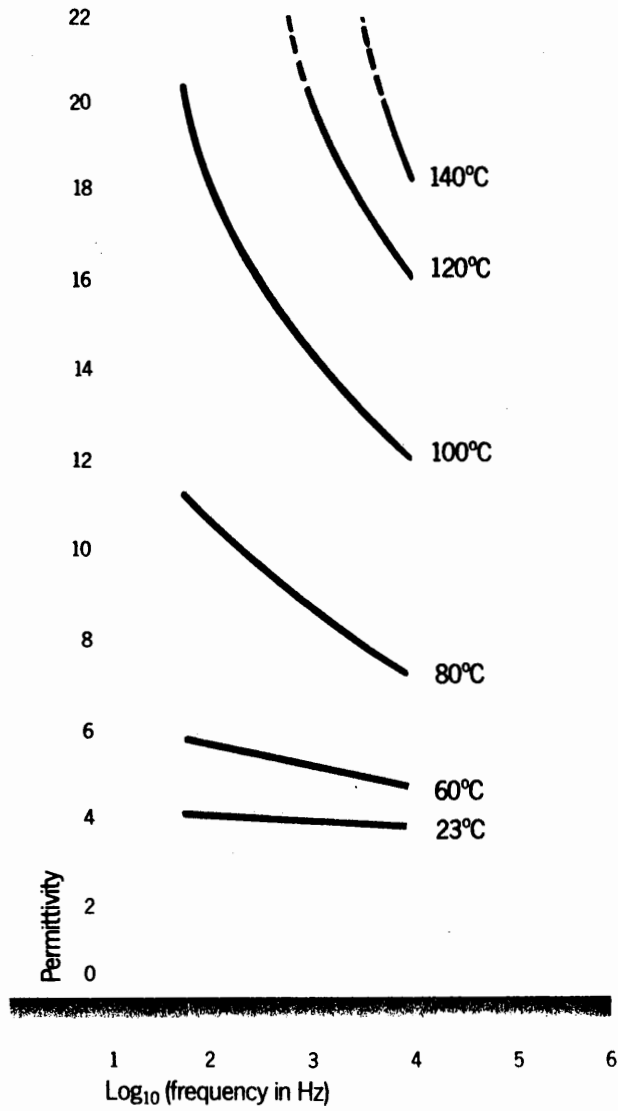
Figure 1: Relative permittivity for PA66, dry as moulded, as function of frequency
for different temperatures (Maranyl A100, ex. ICI) [48]
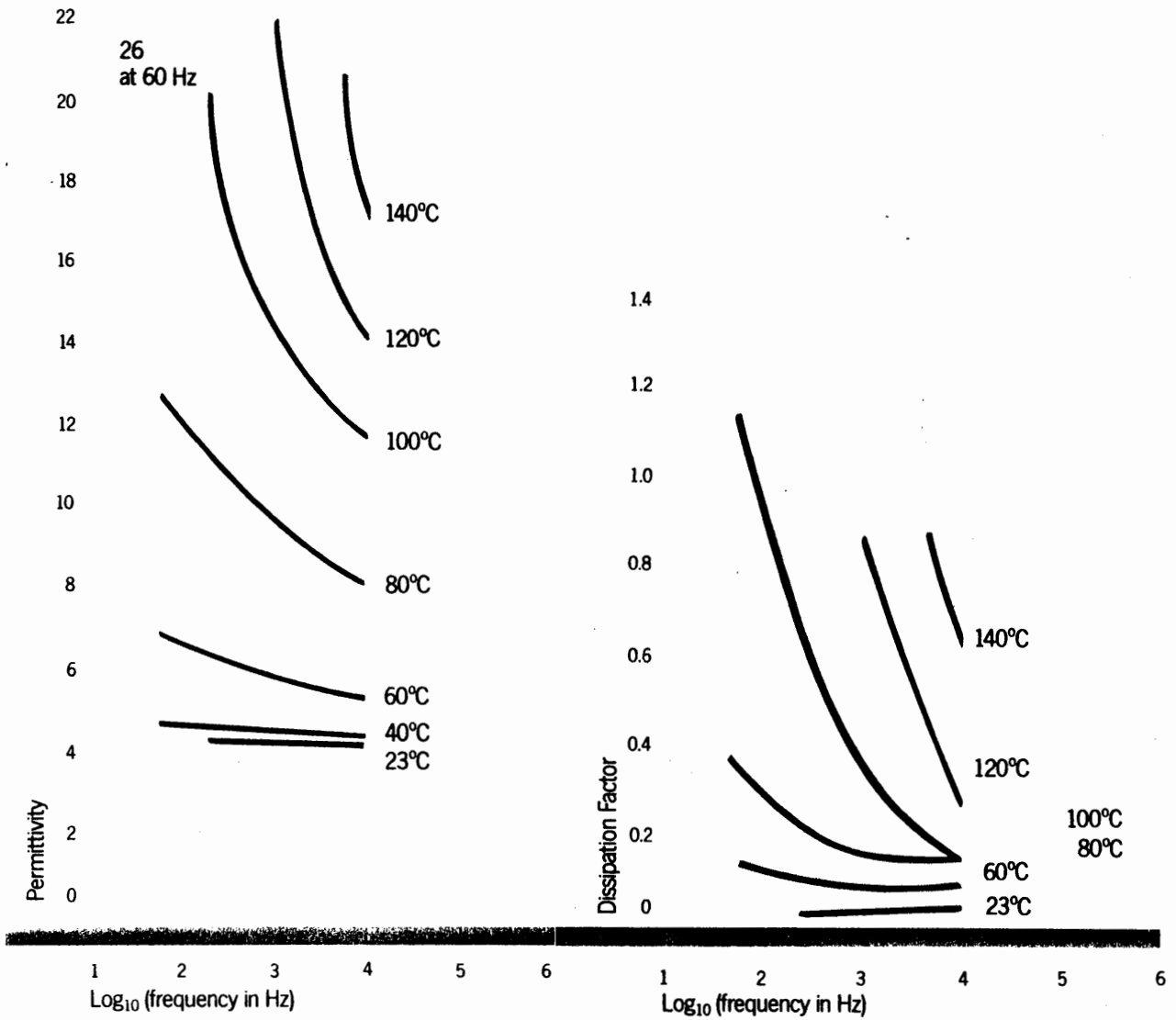
Appendix 1

Figure 2: Relative permittivity (a) and dissipation factor (b) for PA66-GF33, dry as moulded, as function of frequency for different temperatures (Maranyl A190, ex. ICI) [48]
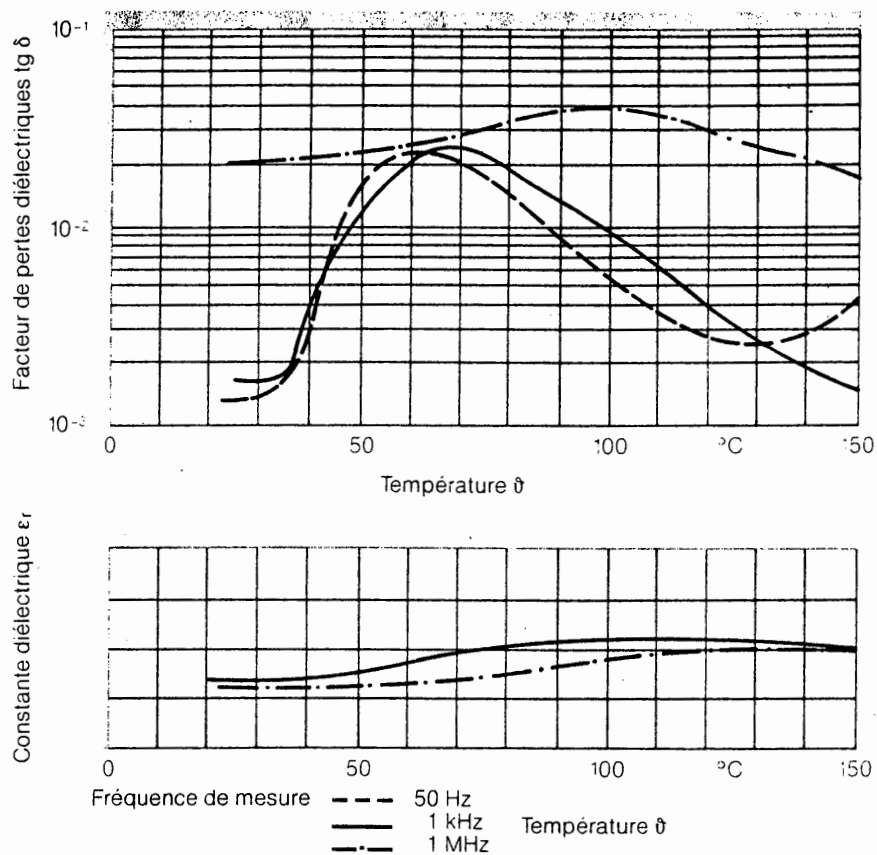
Appendix 1

Figure 3: Relative permittivity and dissipation factor for PBT as function
of temperature at 3 different frequencies (Pocan B 1505, ex. Bayer) [39]

Appendix 1
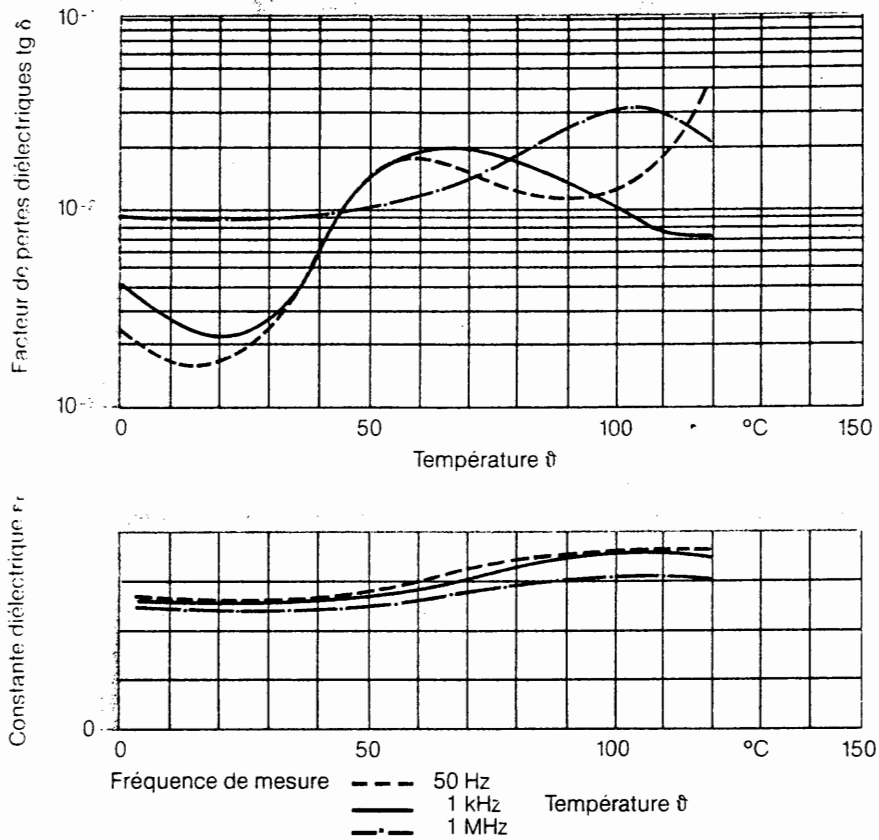
Figure 4: Relative permittivity and dissipation factor for PBT-GF30 as function of temperature at 3 different frequencies (Pocan B 3235, ex. Bayer) [39]

Appendix 1
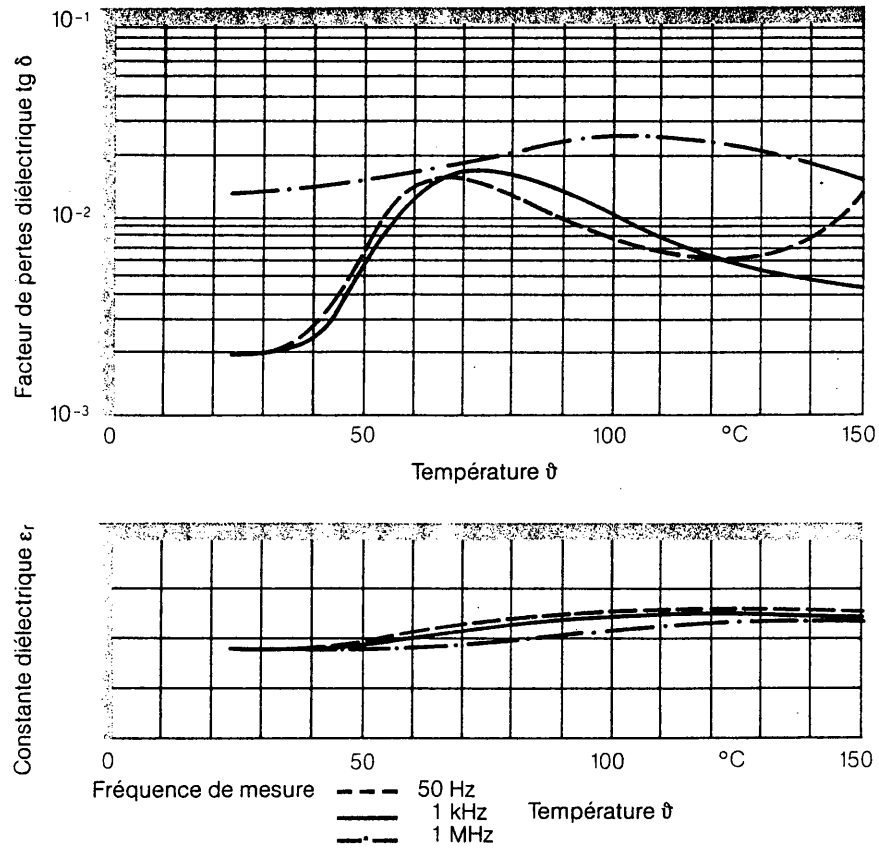
Figure 5: Relative permittivity and dissipation factor for PBT-GF30-FR as function
of temperature at 3 different frequencies (Pocan B 4235, ex. Bayer) [39]

Appendix 1
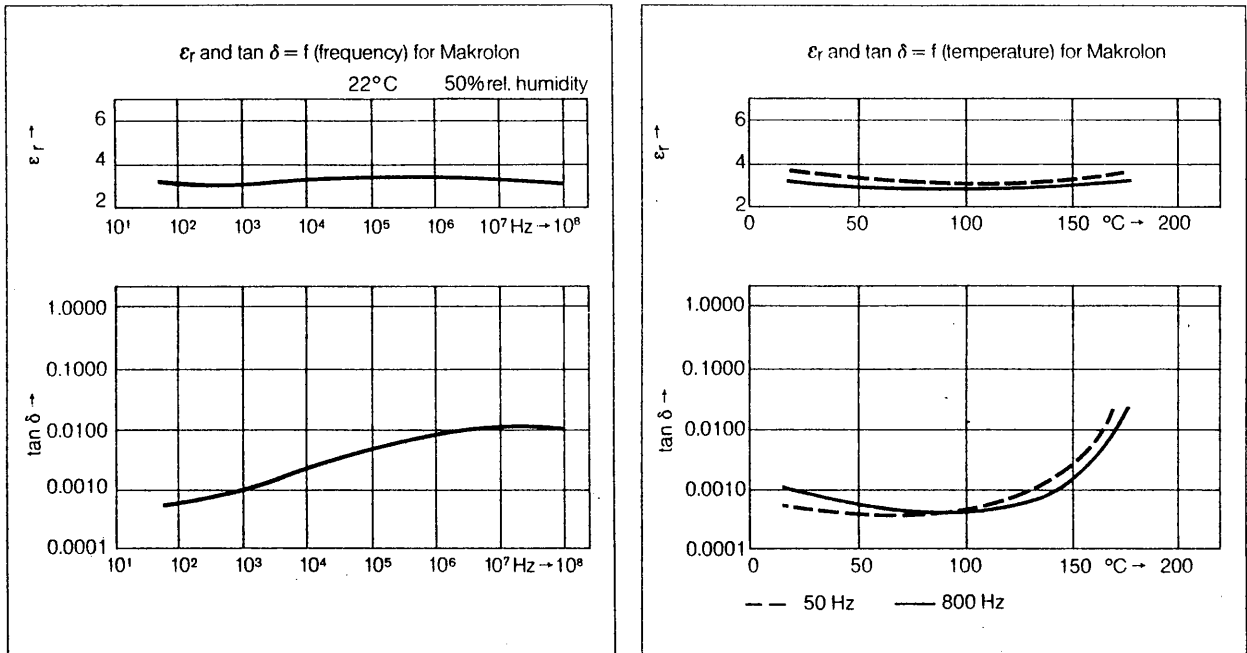
Figure 6: Relative permittivity and dissipation factor for PC
as a function of temperature and frequency [40]
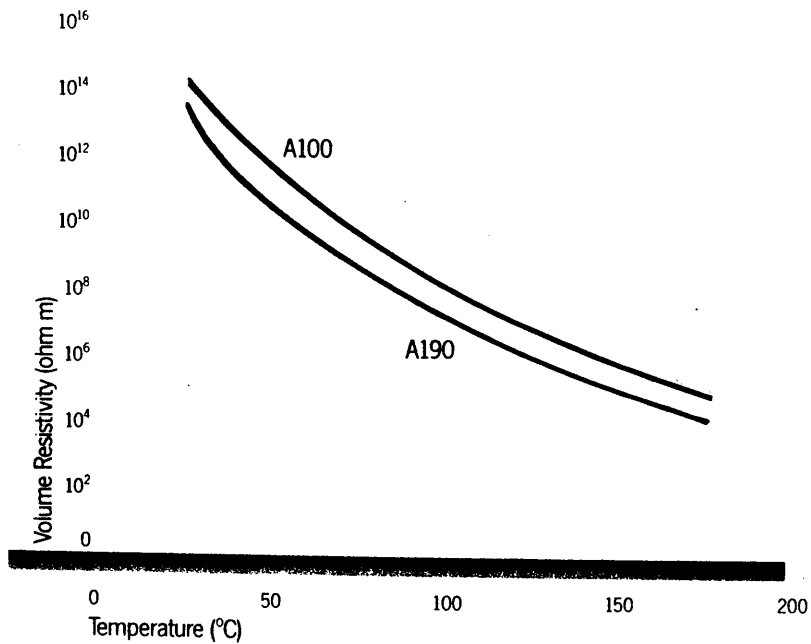
Figure 7: Volume resistivity of as function of temperature for
PA66 (Maranyl A100, ex. ICI) and PA66-GF33 (Maranyl A190, ex. ICI) [48]
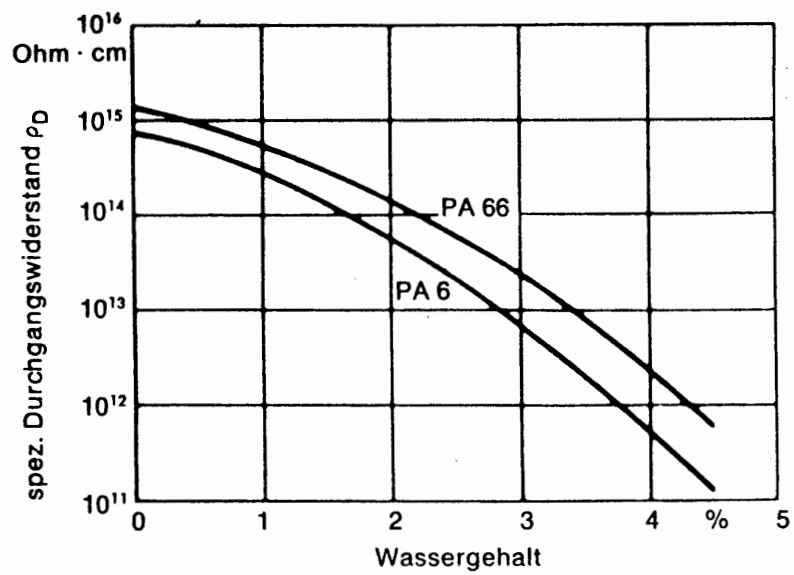
Appendix 1

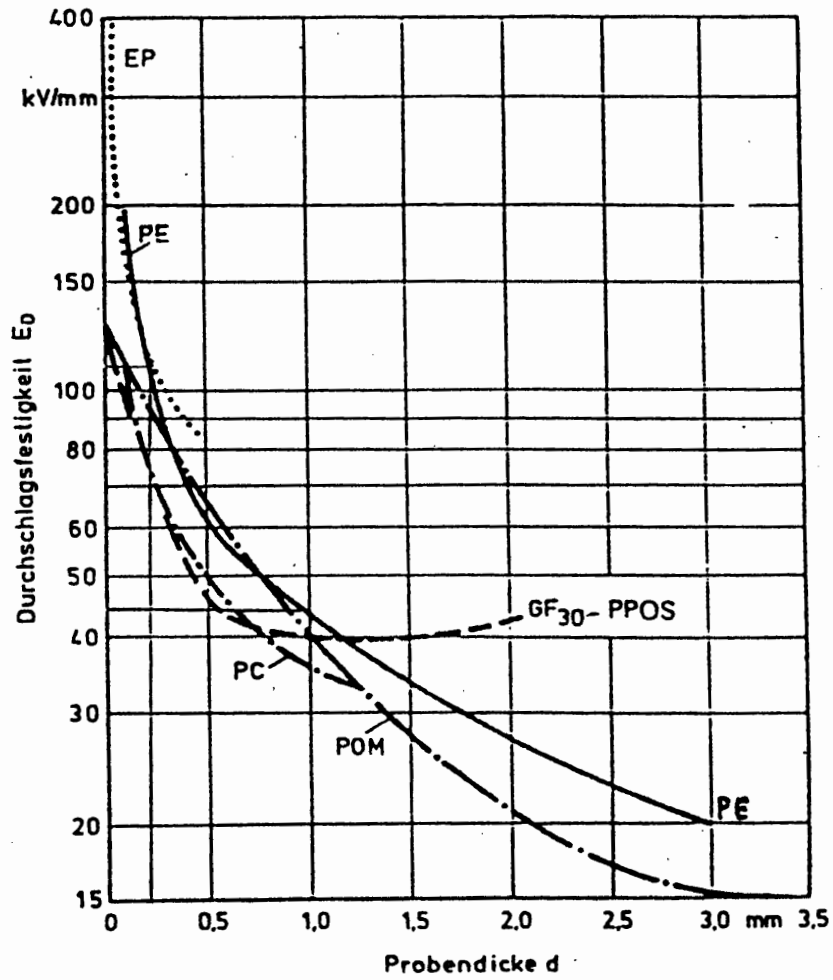**Figure 8:** Volume resistivity as function of moisture content for PA6 and PA66 [49]

Appendix 1

Figure 9: Dielectric strength as function of specimen thickness for a.o. PC, POM and PE [46]
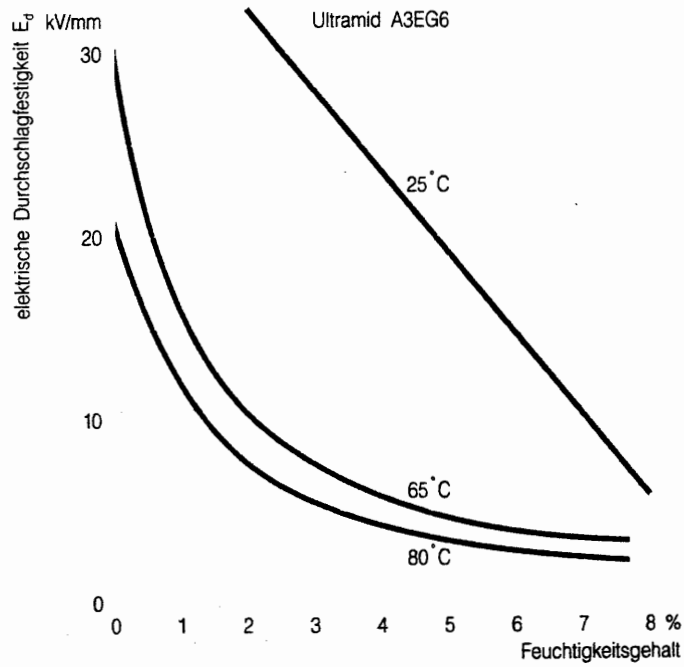
Appendix 1

Figure 10: Dielectric strength as function of moisture content at different temperatures for PA66-GF30 (Ultramid A3EG6, ex. BASF)(DIN 53481; thickness 3mm) [38]
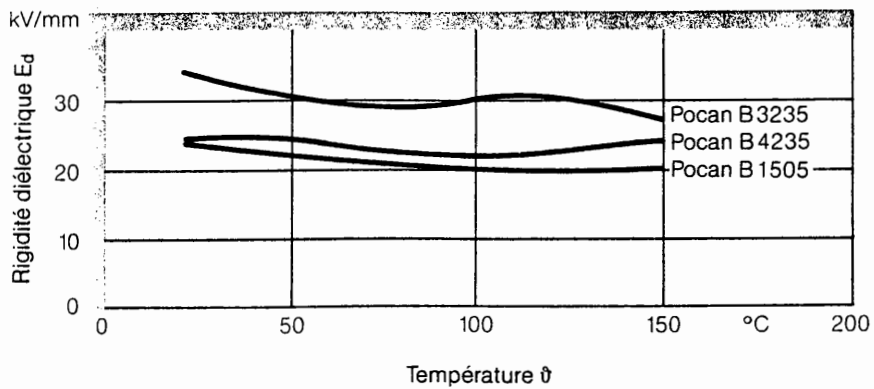

Figure 11: Dielectric strength as function of temperature for respectively PBT, PBT-GF30 and PBT-GF30-FR (respectively, Pocan B 1505, B 3235 and B 4235, ex. Bayer) [39]
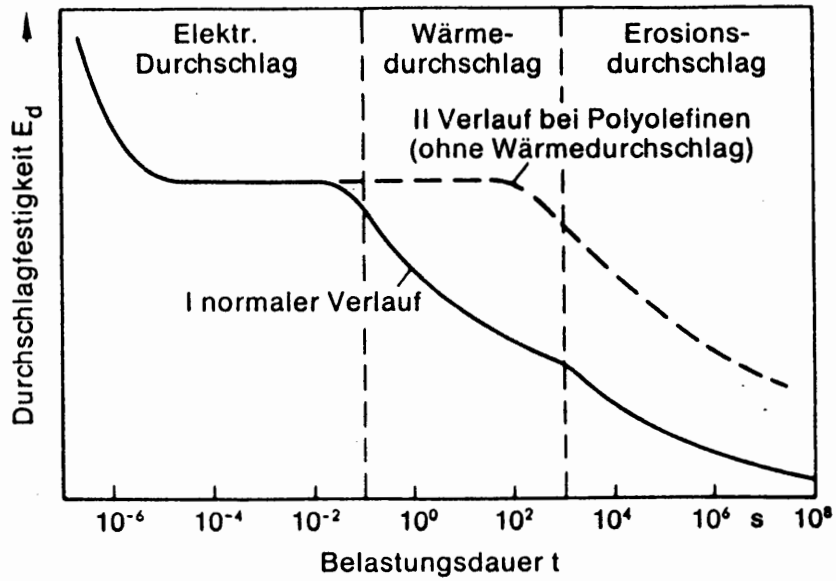
Appendix 1

Figure 12: Schematic presentation of the dielectric strength as function of time [49]
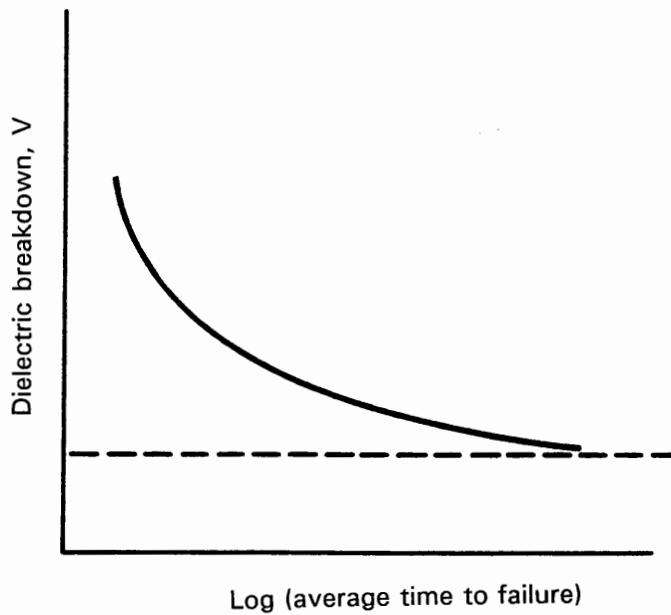

Figure 13: Voltage endurance curve. Effect of continuous dielectric stress on time to failure [7]

APPENDIX 2

Requirements for flame retardant glass fibre reinforced polyamide 66

Below list of requirements, inluding their weight factor, for halogen and red phosphorous free PA66-GF-FR. The list is stemming from one of the largest companies in the electro-technical industry.

Anforderungsprofil "PA"

Funktionsmerkmale (functional requirements)	Wich-tung	Design requirements
frei von Halogen und rotem Phosphor	10	Halogen < 50 ppm, nicht als Additiv
Entflammbarkeit	10	UL94 V1 bei 0,8 mm, sämtliche Farben
Reißdehnung	10	2,2 % trocken, > 2,5 % erwünscht
CTI (Kriechstromfestigkeit)	10	400 V Minimum, nach IEC 112 - kleinere Werte müssen in Abhängigkeit von der Teilegeometrie diskutiert werden
Abriebfestigkeit	10	Nur im Geräteversuch zu prüfen - keine Korrelation mit Laborversuchen
Schlagzähigkeit	10	Charpy 25 KJ/m² (40mm Spannweite)
Durchschlagfestigkeit	10	Wie Ultramid A3X3G5
Gradbildung	10	Mindestens so gut wie UltramidA3X3G5
Teilekosten	10	Granulatpreis < 11 DM/l Zykluszeit wie bei Ultramid A3X3G5 Reinigungszyklus am Werkzeug >100.000 Schuß Werkzeugstandzeit >1.000.000 Schuß Heißkanalsystem wird langfristig bevorzugt Wiederangußverwertung min. 30 % kein Vortrocknen des Granulats oder Tempern des Teils
Füllverhalten	9	Spirallänge wie Ultramid A3X3G5
E-Modul	9	10 GPa (Bosch-Siemens) sonst 5 GPa - kann diskutiert werden
Entformungsverhalten	8	Wie Ultramid A3X3G5

Funktionsmerkmale (functional requirements)	Wich-tung	Design requirements
RTI (Dauereinsatztemperatur)	8	RTI 105 °C mit Schlag, gemäß UL
Schmelzestabilität	8	10 min. Aufenthaltsdauer mind. in der Schnecke
Toxische Gase beim Spritzgießen	8	
Schuß zu Schuß Konstanz	7	Wie Ultramid A3X3G5
HDT (Wärmeformbeständigkeit)	6	HDT/A > 200 °C
Angußrecycling	6	35 % bei kontinuierlicher Zuführung des gemahlenen Angusses (50 % wünschenswert)
Polymerrecycling	5	Polyamid 1. Wahl - aber andere sollten auch angeschaut werden
Schwindung und Verzug	5	Wie für Ultramid A3X3G5
Wasseraufnahme	5	Wie für Ultramid A3X3G5 oder besser
Einfärbbarkeit	3	Ral 7035, jedoch schwarz und naturfarben wichtiger
Zugfestigkeit	3	> 90 MPa
Aussehen der Teile, Oberfläche	2	Wie für Ultramid A3X3G5
Recycelbar (kein Antimon, Cadmium und andere Gefahrstoffe)		
100 % mechanisches Recyceln bei sortenreinem Tellerückführen		

- nicht aufgeführte Eigenschaften sind entweder nicht relevant oder ergeben sich durch andere Eigenschaften
-Prüfnormen gemäß Campus
- Wichtung: Maß für die Möglichkeiten, Nichterfüllung durch andere Maßnahmen zu korrigieren

APPENDIX 3

List of typical ETP grades

Compound	Grade	Supplier
PA66	Durethan A 30 S	Bayer
PA66-FR	Durethan KU 2-2227	Bayer
PA66-GF30	Durethan AKV 30	Bayer
PA66-GF25-FR	Ultramid A3X2G5	BASF
PBT	Pocan B 1305 Vestodur 2003	Bayer Hüls
PBT-FR	Pocan KL1-7503 Vestodur 2002-FR1	Bayer Hüls
PBT-GF30	Pocan B 3235 Vestodur GF30	Bayer Hüls
PBT-GF30-FR	Pocan B 4235 Vestodur GF30-FR1	Bayer Hüls
PC	Makrolon 2800	Bayer
PC-FR	Makrolon 6385/6485	Bayer
PC-GF20	Makrolon 8035	Bayer
PC-GF20-FR	Makrolon 4235	Bayer

APPENDIX 4

List of symbols

C	Material capacitance
C_v	Specific heat at constant volume
ϵ	Material dielectric constant
ϵ_0	Dielectric constant of vacuum
ϵ_r	Relative permittivity or dielectric constant
E	Field strength
E_d	Dielectric strength
P	Loss power
R_{OA}	Surface resistance
R	Resistivity
S	Specific gravity
$\tan \delta$	Dissipation factor or loss tangent
T_m	Melting temperature
V	Volume
ω	Frequency

APPENDIX 5

List of Abbreviations

ABS	Acrylonitrile-butadiene-styrene resin
ac	Alternating current
CAMPUS	Computer Aided Material Preselection with Uniform Standards
CTI	Comparative tracking index
CUT	Continuous use temperature
dc	Direct current
GF	Glass fibre
E/E	Electrical and electronic
EMI	Electromagnetic interference
ETP	Engineering thermoplastic
FR	Flame retardant
HDT	Heat deflection temperature
IEC	International Electrotechnical Commision
LCP	Liquid crystal polymer
PA	Polyamide
PAEK	Polyarylether ketone
PAI	Polyamide-imide
PAS	Polyarylsulfone
PBT	Poly(butylene terephthalate)
PC	Polycarbonate
PCB	Printed circuit boards
PCT	Poly(1,4 cyclohexylenedimethylene terephtalate)
PEEK	Polyetherether ketone
PEI	Polyether imide
PEK	Polyether ketone
PES	Polyethersulfone

Appendix 5

PET   Poly(ethylene terephthalate)

POM   Polyacetal

PPE   Polyphenylether

PPO   Polyphenyloxide

PPS   Polyphenylene sulfide

PS   Polystyrene

PSU   Polysulfone

PVC   Polyvinyl chloride

R.H.   relative humidity

UL   Underwriters Laboratories Inc.

VDE   Verband Deutscher Elektrotechniker

VPS   Vapour phase soldering

VST   Vicat softening temperature

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