Taking the next step ahead to electrify mobility with polycarbonates

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Abstract: Innovation in polycarbonates never stops. High-performance materials like flame retardant Bayblend® FR (PC+ABS FR) and Makrolon® (pure polycarbonates) grades, are already proven solutions for Li-Ion battery packaging in the EE industry for decades. Now, they have been successfully transferred to mobility Li-Ion battery modules, cell holders, and top covers among other applications. The already low carbon footprint of these polycarbonates can be further reduced by using Covestro's more sustainable RE grades based on waste and residual feedstocks from biological sources[1].

Moreover, Covestro developed two new premium material portfolios. The Makrolon® TC portfolio offers thermal conductivity, and electrically conductive or electrically insulating grades, to support uniform temperature distribution in battery modules hence improving Li-Ion cell lifetime.

Additionally, Covestro launched two new isotropic and flame retardant polycarbonates with a Comparative Tracking Index[2] CTI of 600 V for Li-Ion batteries, power electronics, and EE applications offering new options to overcome known plastic's warpage and scrap rate problems at Tiers and OEMs.

Keywords: polycarbonates, innovation, batteries, carbon footprint, thermal conductivity, CTI.

1. Introduction

1.1 Covestro – one of the leading premium polymer suppliers

Covestro is among the leading suppliers of premium polymers globally. Our materials and application solutions are found in nearly every area of modern life. Innovation and sustainability are the driving forces behind the continuous development of our products, processes and facilities. Covestro produces precursors for polyurethane foams, coatings, adhesives and sealants, as well as high-performance thermoplastics like polycarbonates (PC) or thermoplastic polyurethanes (TPU), including films thereof. The company works continuously to further advance products, technologies, and application solutions [1].
Automotive is one of the most important industries for Covestro. Hence, many of our innovations were introduced to this industry over the last few years, for example: Covestro introduced visions of new exterior and interior designs for electric vehicles at the K-fair 2016, 2019 and 2022 [2,3,4]. The automotive industry is facing significant disruption as the shift towards electrification opens up new options for plastics in Li-ion batteries and electric powertrains. The boundaries between the electrical and automotive industry will be less clear in the future causing a paradigm shift [5].

From materials for EV frontends with embedded functional electronics to realizing a seamless mobility interior concept which makes the electric vehicle a connected multifunctional living and working space, Polycarbonates enabled new solutions for the right application at the right time.

1.2 Unique properties of polycarbonates

Makrolon®, our amorphous and dimensional stable polycarbonate (PC) is well-known in vehicles interior, exterior and lighting applications such as displays, switches and trims, front-end modules, headlamp lenses, reflectors as well as interior and exterior LED applications. It provides a unique combination of transparency, impact and temperature resistance. For high temperature applications, Apec®, a high temperature resistant polycarbonate, is an excellent choice, e.g., in headlamp applications.
Bayblend®, a PC+ABS blend, is characterized by its excellent balance of low-temperature toughness and processing behaviour making it the material of choice for both interior and exterior applications. Makroblend® (PC+PBT, PC+PET) delivers an excellent toughness as an engineering thermoplastic and is therefore used in exterior applications.
In the Electrical industry, light switches, cable channels, LED housing, smart meters, housing for 5G antennas and electric charging stations are also made of polycarbonate. Last but not least, Covestro developed materials for notebook battery packaging already years ago. Both the intrinsic flame retardance of Makrolon® and the phosphate-based flame retardance technology of Bayblend® FR play an increasing role in EE [5].

1.3 New bio-attributed and more sustainable materials – "we will be fully circular"

Recently, Covestro launched its new more sustainable RE product series[1] to the market. Waste and residual materials from biological sources are introduced into the value chain from our mass balanced bio-circular products as a drop-in solutions towards full circularity [6]. The physical, mechanical, thermal, optical, weathering and processing properties of Makrolon® RE, Apec® RE, Bayblend® RE and Makroblend® RE resins are identical to their corresponding conventional resins but with reduced carbon footprint and fossil resources saved.

2. How we support the electrification

Traditionally, automotive manufacturers have mainly used semi-crystalline materials in proximity to conventional combustion engines for good reasons. The surrounding conditions under the hood were not favorable for polycarbonates. Now, the electrification of the automotive industry brings new requirements to electric vehicles (EVs) opening a path for new various material classes.

Electric vehicles are increasingly become moving electric devices, merging classic car manufacturing and the electronics industry. Besides having rechargeable Li-Ion batteries, new components such as inverters, converters, HV connectors, and power distributors are needed as well as more sensors and vehicle control units. For some of these applications, thermal management is key in terms of safety and battery lifetime whereas impact protection is achieved by the use of crash absorbers [5].

Covestro offers a broad portfolio of high performance polycarbonate-based materials that include Makrolon® and Bayblend® for EV battery and powertrain housings. Typical applications in this ecosystem require properties such as ductility and toughness, fire and electrical resistance, and dimensional stability over a wide temperature range that our portfolio covers thoroughly. In terms of thermal management, our new thermally conductive and electrically insulating Makrolon® TC portfolio is a solution for applications that require hot spots reduction and uniform temperature distribution. Likewise, polycarbonates offer high transparency for both LiDAR and Radar frequencies for sensor applications [5, 7].

For high voltage applications, Covestro introduced new (CTI/FR)[2] grades at K-Fair 2022 which combine flame retardancy and high electrical tracking resistance of 600 V while keeping the advantageous properties of amorphous thermoplastics like their dimensional stability and low warpage.

2.1 Battery packaging with dimensional stable polycarbonates offering low warpage behavior

Due to the amorphous nature of our polycarbonates and polycarbonate blends, their mechanical properties remain nearly constant over the battery operating temperature range without any reinforcement. In addition, battery manufacturers select Bayblend® and Makrolon® due to their high dimensional stability, low and predictable warpage, low moisture absorption, and inherent flame retardance. Polycarbonates have demonstrated proven performance in packaging for a variety of battery cell formats used in electric vehicles with the added benefits of optimized processing, low scrap rates and scalable manufacturing.

A typical material for cylindrical cell holders is our unreinforced PC+ABS Bayblend® FR3040 EV that provides a UL94V-0 rating at 1.0 mm while offering a sufficient transmission for UV curing of adhesives through the material, being this another advantage of the amorphous polymer structure of polycarbonates [8]. UV curing allows fixing cylindrical battery cells at specific locations for faster assembly. Transparent materials like our flame retardant polycarbonate Makrolon® 6555 can be used for this purpose as well. When flame retardance at thinner walls is required, we offer grades like Bayblend® FR3080 EV with UL94V-0 ratings down to 0.75 mm.

For prismatic and pouch cells modules our customer can go for the unreinforced Bayblend® FR3010 for busbar carriers and if a higher elastic modulus is required, Bayblend® FR3060 EV is a perfect match for end plates [9, 10].

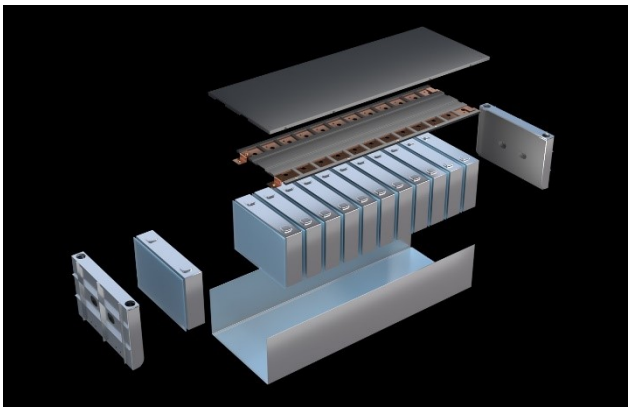

Figure 6: Illustrated prismatic cell battery module with top cover, busbar carrier and end plates.

Additionally, in our more sustainable polycarbonate portfolio, we offer bio-circular attributed drop-in solutions like Bayblend® FR3042 RE, Bayblend® FR3010 RE and Makrolon® 6165X RE with significant carbon footprint reduction while retaining identical properties as primary fossil based versions[1].

As part of expanding our material portfolio according to market requirements, we have recently introduced new additions to our Bayblend® and Makrolon® portfolio. Our new grades, Bayblend® FR3015 CTI and Makrolon® FR6019 CTI, provide an increased electrical tracking resistance CTI[2] tailored to meet the varied customer needs for electric vehicle battery packaging applications, power electronics and EE applications.

2.2 Heat management for electric vehicles with Makrolon® TC, including EMI shielding properties

Usually thermoplastic materials are thermal insulators, however, Covestro introduced a new portfolio of thermally conductive polycarbonates, Makrolon® TC, allowing our customers to choose between electrically conductive and electrically insulating materials, that are also flame retardant according to the UL94 V classification. Electrically conductive Makrolon® TC grades provide a thermal conductivity[3] of up to 16 W/mK in plane and 1.4 W/mK through plane whereas electrically insulting grades offer up to 1.4 W/mK in plane and 0.3 W/mK through plane. These thermoplastic resins combine heat management capability with key-strengths of polycarbonates, such as excellent dimensional stability and high heat resistance. However, efficient heat dissipation is not only a matter of the thermal conductivity physical value, but rather synergy with cooling element designs. With the right design approaches, Makrolon® TC grades have proven in various applications to be able to reach the same thermal management performance as metal heat sinks, while at the same time these materials open the door to potential cost reductions, lower manufacturing complexity, reduced weight and a higher design freedom. Covestro has a vast experience in supporting our customers in part design, mold filling- and thermal simulations, to achieve their heat dissipation goals.
Makrolon® TC polycarbonate in EV applications opens the door to new possibilities, such as thermally conductive but electrically insulating cell holders, housings that dissipate the energy of power electronics and control units, or replacing metals with more flexible heat sink designs. Makrolon® TC can be used to protect electronics and to enable efficient heat dissipation at the same time.

For EV batteries, thermally conductive polycarbonates can be used for cell holders or cooling plates to support cell life-time by homogeneously distributing the heat and reducing the overall temperature within the module and pack. As an example, own simulations of a power tool Li-Ion battery pack with cylindrical cells showed a decrease of the cell temperature during charging/discharging of about 3°C when using a cell holder with a simple geometry made of Makrolon® TC110 [11]. Optimization of the cell holder design can decrease the temperature to an even lower level.
Lithium-ion batteries cell holders made of thermally conductive Makrolon® TC have proven to dissipate heat effectively by reducing the thermal gradient across battery packs and extending the battery cell life. In addition, electrically insulating Makrolon® TC110 and Makrolon® TC110 FR[5] grades used in battery housings pass impact and vibration tests required for many battery-powered portable devices.
Due to the increasing performance requirements of control units and power electronics, heat dissipation efficiency is needed for low and high voltage EV circuits. For moderate heat dissipation as observed in low voltage circuits, housings made of Makrolon® TC110 FR[5] are advisable. On the other hand, when rather higher heat dissipation is needed, electrically conductive Makrolon® TC629 is the material of choice. Both materials could be easily combined in a 2K-shot injection process to take advantage of both electrically conductive and insulating properties as shown in Figure 6. To showcase our materials, a battery module and a vehicle control unit made of Makrolon® TC were exhibited recently at the K-fair 2022 in Düsseldorf, Germany.

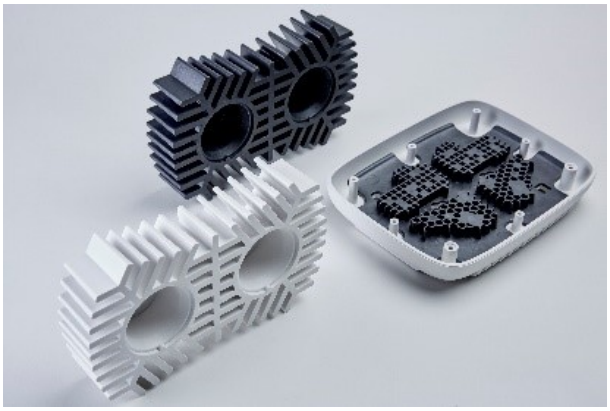

Figure 7: 2K-shot injection molded heat sinks used to combine electrically insulating (white part) and electrically conductive materials (black part).

Another advantage of using Makrolon® TC is part weight and complexity reduction while meeting required cooling efficiency. This allows smart replacement of die-cast Aluminum parts and improvement of design space which ultimately leads

to increasing energy density and therefore vehicle range. As an example for an aluminum replacement in an actual heat management scenario, we recently introduced our new Heatsink Screener using Makrolon® TC polycarbonate for LED lightings. The Heatsink Screener is a web-based tool to quickly compare Makrolon® TC versus cast aluminum for heatsinks. It also highlights the weight savings potential of Makrolon® TC over aluminum, while maintaining similar heat management performance [11].
Besides efficient thermal management, Makrolon® TC offers also the benefit of an excellent dimensional stability e.g., reflected in low and nearly isotropic thermal expansion coefficients, close to those of Aluminum and Copper. Parts with high dimensional accuracy and low warpage tendency can be made from these resins, which may enable automation in battery assembly for electric vehicles, thus reducing costs in EV manufacturing.
In addition, our electrically conductive Makrolon® TC grades can be used to shield sensitive components against electromagnetic interference in higher frequency ranges. Due to their electrical conductivity, these grades provide a shielding effectiveness of up to 55 dB at 3 mm thickness for frequencies in the range between 1 and 18 GHz based on Covestro internal testing[5].

2.3 Newly developed (CTI/FR)^2 polycarbonates combine the best of two material worlds

Covestro polycarbonates offer excellent electrical properties that have been proven in manifold applications in the EE industry. The electrical strength and specific resistivities are superior or at the same level in comparison to other technical thermoplastics used in electrical applications.
As the EE and automotive industry are merging, many requirements for part design and part safety coming from the EE industry are adopted by the automotive industry. Hence, the amount of applications requiring flame retardancy is steadily increasing. Reducing component size and with that distances between electrical tracks in order to increase functional or energy density is driving the need for materials that can provide both, excellent FR properties in combination with the highest tracking resistance.
Engineers working in the area of automotive powertrain generally use semi-crystalline plastics due to the harsh environment of combustion engines. Typically, those materials are in favor when it comes to tracking resistance often offering the highest rating of 600V, while lacking of dimensional accuracy and stability. As a new option for the industry Covestro recently launched two unique products, Bayblend® FR3015 CTI and Makrolon® FR6019 CTI, which combine both, a CTI^2 of 600V and excellent flame resistance with the dimensional stability as well as the isotropic and precise behavior of amorphous polycarbonates for new applications in Li-Ion batteries and power electronics.

Figure 8: High voltage components, exemplary representation, orange color indicates high voltage.

Bayblend® FR3015 CTI is a flame retardant and ductile PC blend, developed for Li-ion battery applications, such as cell holders or bus bar carriers. Characterized by a high Vicat temperature of 120°C this unreinforced and low warpage grade can be used for components with increased safety requirements, e.g. a CTI of 600V combined with a UL94V-0 rating at 1.5mm, in addition to the already available Bayblend® FR solutions. The high Vicat temperature results in stable mechanical properties over its entire temperature range, thus making glass-fiber reinforcement unnecessary.

Makrolon® FR6019 CTI is an unreinforced and flame-retardant polycarbonate with UL94V-0 classification at 1.5mm with a high CTI of 600V designed for applications in the power electronics and can also be used in Li-ion batteries. It is impact-resistant and has an even higher Vicat temperature of 131°C. Below the softening temperature, the mechanical properties remain nearly constant which again makes any glass-fiber reinforcement unnecessary. As a result, Makrolon® FR6019 CTI is distinguished by its thermally isotropic behavior and low warpage.

Both, Bayblend® FR3015 CTI and Makrolon® FR6019 CTI, are opaque grades and easy to color. Customers should bear in mind that the color, being part of the recipe, might modify the CTI value. Covestro therefore offers its customers technical support.

Table 2: Material properties of Bayblend® FR3015 CTI and Makrolon® FR6019 CTI.

Properties	Bayblend® FR3015 CTI[2]	Makrolon® FR6019 CTI[2]
CTI[2] (IEC60112)	600 V	600 V
Burning behavior[1,2] (UL94, natural color))	V-0 at 1.5 mm	V-0 at 1.5 mm
Electrical strength (IEC 60243-1 / 1mm)	36 kV/mm	31 kV/mm
Vicat temperature (ISO 306, 50 N; 120 °C/h)	120 °C	131 °C
HDT A (ISO 75-1,-2 / 1.8 MPa)	101 °C	112 °C
MVR (ISO 1133)	22 cm³/10 min (260 °C/ 5 kg)	13 cm³/10 min (300 °C/ 1,2 kg)
Tensile modulus (ISO 527-1,-2)	2370 MPa	2470 MPa
Density (ISO 1183-1)	1180 kg/m³	1200 kg/m³
Colors[2]	white, grey, black, orange, natural	white, grey, black, orange, natural

The CTI test according to IEC60112 consists of two electrodes placed in a pre-defined distance on the substrate. Starting between 300 and 350V, at each voltage test level 50 drops of a conductive solution is applied between the electrodes. If a voltage level is successfully tested, it can be gradually increased until it reaches the maximum test voltage of 600V. If a voltage level failed in the test, the CTI is defined as the last voltage level having passed the test.

3. Technical support of our customers

With R&D hubs in North America, Europe and Asia/Pacific, we are globally connected and can serve our customers on a regional basis.
During the conception and design phase, we can offer support with comprehensive mechanical and rheological simulations. To ensure mechanical integrity of the application, we can cover static and dynamic mechanical simulations. Tool and part design is supported by rheological simulations to guarantee processability of the part. When it comes to production, we can provide assistance with comprehensive technical labs equipped with injection molding machines from small to large scale, including highly automated ones for pilot production support. In addition, we provide local support at the production facilities of our partners to support commissioning or solve issues during mass production.

3.1 Example: Detailed investigation of dimensional stability of polycarbonates to reduce scrap rates

Comparing achievable tolerances, shrinkage and warpage behavior of glass-filled semicrystalline materials to Covestro flame retardant products such as Bayblend® FR3040 EV, there are clear advantages. Although this may seem like a difficult comparison, in some applications the glass-filled products like PA6 are used not because of the need for high modulus, but because the glass fibers reduce their shrinkage and stabilize the base resin. Figure 1 and 2 show the warpage magnitude and distribution of a part injected with Bayblend® FR3040 EV and a glass-filled semicrystalline material, respectively. When comparing a typical part of approximately 200 mm in diameter, results indicate 1.5 times lower warpage with unfilled Bayblend® PC/ABS than with glass filled semicrystalline materials. In the same part geometry, Bayblend® also exhibits a lower standard deviation in warpage making the warpage range 18 times narrower[4]. As parts become larger and less geometrically stiff, these differences tend to grow as well.

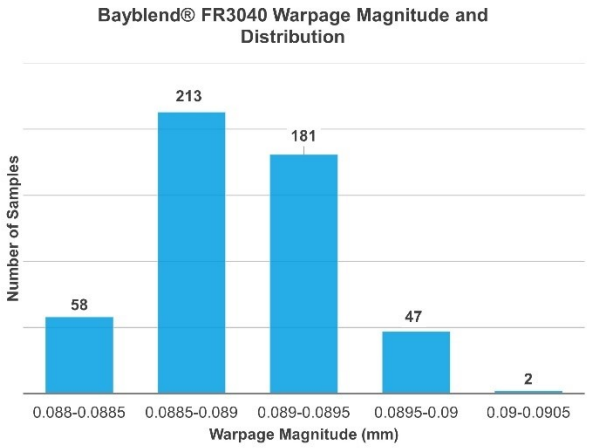

Figure 1: Warpage magnitude and distribution of a 200 mm round part made of Bayblend®® FR3040 EV.

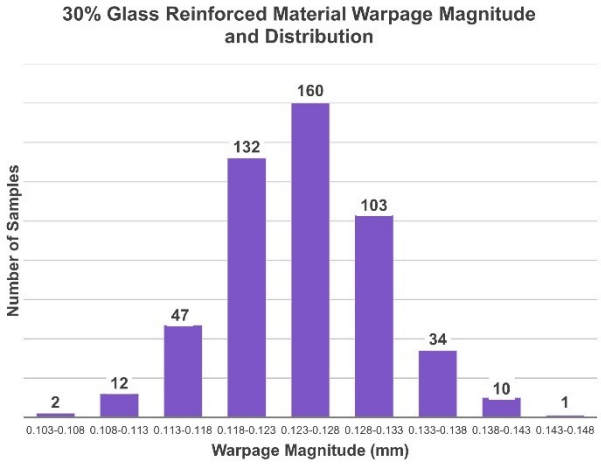

Figure 2: Warpage magnitude and distribution of a 200 mm round part made of 30% glass reinforced PA6.

In cases where a higher modulus is required, glass reinforced (PC+ABS) as Bayblend® T88GF30

showed both lower warpage magnitude and a narrower distribution compared to a similarly glass filled PPO+PA blend. Warpage distribution frequency for a 1000 mm flat part, see Figure 3, is shown in Figure 4 and 5 for both materials studied, respectively. Lower magnitude and the lower standard deviation of warpage for Bayblend® means more consistent parts with up to 6 times lower scrap, as shown in Table 1, where 500 parts' warpage was compared when made of 30% glass filled PC+ABS and a 40% glass-filled semicrystalline material[3].

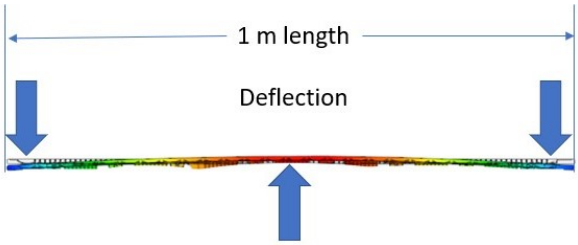

Figure 3: 1000 mm flat part warpage calculated using Bayblend® T88GF30 and 40% GF PPO/PA blend.

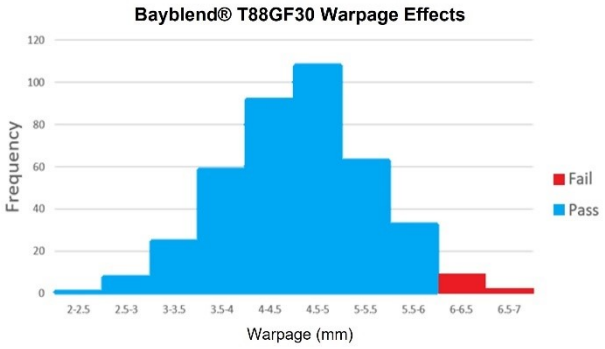

Figure 4: Warpage magnitude and distribution for a 1000 mm long flat part injected with Bayblend® T88GF30.

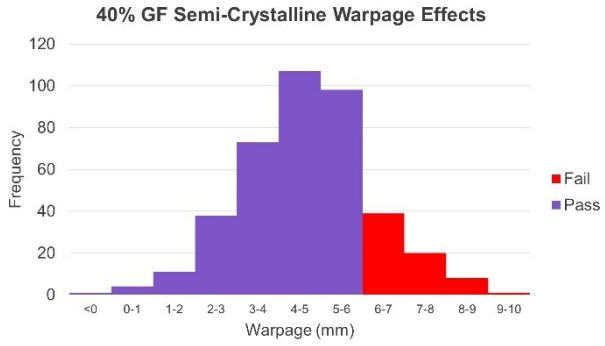

Figure 5: Warpage magnitude and distribution for a 1000 mm long flat part injected with 40% GF PPO/PA.

Table 1: Warpage and scrap rate comparison when using PC+ABS glass-filled versus glass-filled semicrystalline materials[3].

	Bayblend® T88GF30	40% GF Semicrystalline
Standard deviation	0.79	1.51
Acceptable warpage	6 mm	
Pass	389	332
Fail	**11**	68

Unreinforced Bayblend® exhibits generally isotropic mold shrinkage, and glass reinforced Bayblend® grades tend to have lower differential shrinkage compared to glass reinforced semi-crystalline materials. Although it is theoretically possible to allow for differential mold shrinkage in tool construction, it is not practical in complex parts such as the ones needed in EV battery packaging and in electronic applications. This means the advantage of Covestro products is parts that fit together better and fewer parts out of specification that need to be scrapped. These are critical considerations in assembly operations which require both a high degree of consistent dimensional accuracy and competitive cost efficiency[3].

4. Summary

New properties like thermal conductivity and an increased CTI allow automotive engineers to expand their material portfolio with the aim of using the right material in the right place. Amorphous polycarbonates, which were previously not used in the traditional powertrain, now offer advantages that seemed unattainable in the past. In future, further joint and customer-oriented developments of our materials will enable even more unexpected applications from polycarbonates.

5. Acknowledgement

We would like to express our gratitude to our teams in R&D, application development and product technology, as well as to our sales and market development colleagues who have provided input, resources, and valuable insights to further develop the use of our materials in EV applications for our customers and so take the next step ahead to electrify mobility with polycarbonates.

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7. Glossary

ABS: Acylonitrile butadiene styrene copolymer

CTI: Comparative Tracking Index

EE: Electric and Electronics

EV: Electric vehicles

FR: Flame retardant

K-Fair: Kunststoffmesse Düsseldorf

LED: Light-emitting diode

NC: Natural color

OEM: Original equipment manufacturer

PA: Polyamide

PC: Polycarbonate

PBT: Polybutylene terephthalate

PET: Polyethylene terephthalate

PPO: Poly(phenylene oxide)

TC: Thermally conductive

TP: Trial Product, preliminary material properties

[1] RE Series: Our mass balanced products are accompanied by a Sustainability Declaration according to ISCC PLUS defining the sustainable share and raw material category attributed to the product. According to the ISCC PLUS system document (v.3.3) the bio-circular raw material category, as our RE Series, refers to feedstocks related to waste and residues of biological origin. (ISCC PLUS: https://www.iscc-system.org/wp-content/uploads/2021/08/ISCC-PLUS_V3.3_31082021.pdf)) Our ISCC PLUS Sustainability declaration confirms that the raw material was not intentionally produced and not intentionally modified, or contaminated, or discarded, to meet the definition of waste or residue.

[2] Colors: preliminary, please contact Covestro

[3] Thermal conductivity measurements acc. to ASTM E 1461-01, 23 °C

[5] Preliminary data, depending on part thickness and design

[4] Monte Carlo method was used to create 500 aleatory iterations of the minimum and maximum temperatures recommended to process Bayblend® FR3040 EV and 30% glass fiber reinforced polyamide used as input to perform Moldflow® simulations and subsequently obtain final warpage. Contact Covestro representatives for more details.

[5] Makrolon® TC110 FR will be phased out in Q1, 2024. A successor product will be available.