Polycarbonate

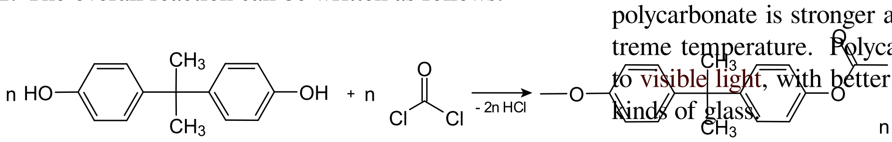
Polycarbonates (**PC**) are a group of thermoplastic polymers containing carbonate groups in their chemical structures. Polycarbonates used in engineering are strong, tough materials, and some grades are optically transparent. They are easily worked, molded, and thermoformed. Because of these properties, polycarbonates find many applications. Polycarbonates do not have a unique resin identification code (RIC) and are identified as "Other", 7 on the RIC list. Products made from polycarbonate can contain the precursor monomer bisphenol A (BPA). Polycarbonate is also known by a variety of trademarked names, including Lexan, Makrolon, Hammerglass and others.

1 Structure

Polycarbonates received their name because they are polymers containing carbonate groups (–O–(C=O)–O–). A balance of useful features, including temperature resistance, impact resistance and optical properties, positions polycarbonates between commodity plastics and engineering plastics.

2 Production

The main polycarbonate material is produced by the reaction of bisphenol A (BPA) and phosgene COCl
2. The overall reaction can be written as follows:



The first step of the synthesis involves treatment of bisphenol A with sodium hydroxide, which deprotonates the hydroxyl groups of the bisphenol A.[5]

$$(HOC_6H_4)_2CMe_2 + 2\ NaOH \rightarrow Na_2(OC_6H_4)_2CMe_2 + 2\ H_2O$$

The diphenoxide ($Na_2(OC_6H_4)_2CMe_2$) reacts with phosgene to give a chloroformate, which subsequently is attacked by another phenoxide. The net reaction from the diphenoxide is:

$$Na_2(OC_6H_4)_2CMe_2 + COCl_2 \rightarrow 1/n\ [OC(OC_6H_4)_2CMe_2]_n + 2\ NaCl$$

In this way, approximately one billion kilograms of polycarbonate is produced annually. Many other diols have been tested in place of bisphenol A, e.g. 1,1-bis(4-hydroxyphenyl)cyclohexane and dihydroxybenzophenone. The cyclohexane is used as a comonomer to suppress crystallisation tendency of the BPA-derived product. Tetrabromobisphenol A is used to enhance fire resistance. Tetramethylcyclobutanediol has been developed as a replacement for BPA.[5]

An alternative route to polycarbonates entails transesterification from BPA and diphenyl carbonate:

$$(HOC_6H_4)_2CMe_2 + (C_6H_5O)_2CO \rightarrow 1/n\ [OC(OC_6H_4)_2CMe_2]_n + 2\ C_6H_5OH$$

The diphenyl carbonate was derived in part from carbon monoxide, this route being greener than the phosgene method.[5]

3 Properties and processing

Polycarbonate is a durable material. Although it has high impact-resistance, it has low scratch-resistance. Therefore, a hard coating is applied to polycarbonate eyewear lenses and polycarbonate exterior automotive components. The characteristics of polycarbonate compare to those of polymethyl methacrylate (PMMA, acrylic), but polycarbonate is stronger and will hold up longer to extreme temperature. Polycarbonate is highly transparent to visible light, with better light transmission than many kinds of glass.

Polycarbonate has a glass transition temperature of about 147 °C (297 °F),[6] so it softens gradually above this point and flows above about 155 °C (311 °F).[7] Tools must be held at high temperatures, generally above 80 °C (176 °F) to make strain-free and stress-free products. Low molecular mass grades are easier to mold than higher grades, but their strength is lower as a result. The toughest grades have the highest molecular mass, but are much more difficult to process.

Unlike most thermoplastics, polycarbonate can undergo large plastic deformations without cracking or breaking. As a result, it can be processed and formed at room temperature using sheet metal techniques, such as bending on a brake. Even for sharp angle bends with a tight radius, heating may not be necessary. This makes it valuable in prototyping applications where transparent or electrically non-conductive parts are needed, which cannot be made from sheet metal. PMMA/Acrylic, which is similar in appearance to polycarbonate, is brittle and cannot be bent at room temperature.

Main transformation techniques for polycarbonate resins:

- extrusion into tubes, rods and other profiles including multiwall
- extrusion with cylinders (calenders) into sheets (0.5–20 mm (0.020–0.787 in)) and films (below 1 mm (0.039 in)), which can be used directly or manufactured into other shapes using thermoforming or secondary fabrication techniques, such as bending, drilling, or routing. Due to its chemical properties it is not conducive to laser-cutting.
- injection molding into ready articles

Polycarbonate may become brittle when exposed to ionizing radiation above 25 kGy (J/kg).[8]

A bottle made from polycarbonate

4 Applications

4.1 Electronic components

Polycarbonate is mainly used for electronic applications that capitalize on its collective safety features. Being a good electrical insulator and having heat-resistant and flame-retardant properties, it is used in various products associated with electrical and telecommunications hardware. It can also serve as a dielectric in high-stability capacitors.[5] However, commercial manufacture of polycarbonate capacitors mostly stopped after sole manufacturer Bayer AG stopped making capacitor-grade polycarbonate film at the end of year 2000.[9][10]

4.2 Construction materials

Polycarbonate sheeting in a greenhouse

The second largest consumer of polycarbonates is the construction industry, e.g. for domelights, flat or curved glazing, and sound walls.

4.3 Data storage

CDs and DVDs

A major application of polycarbonate is the production of Compact Discs, DVDs, and Blu-ray Discs. These discs are produced by injection molding polycarbonate into a mold cavity that has on one side a metal stamper containing a negative image of the disc data, while the other mold side is a mirrored surface. Typical products of sheet/film production include applications in advertisement (signs, displays, poster protection).[5]

4.4 Automotive, aircraft, and security components

In the automotive industry, injection-molded polycarbonate can produce very smooth surfaces that make it well-suited for sputter deposition or evaporation deposition of aluminium without the need for a base-coat. Decorative bezels and optical reflectors are commonly made of polycarbonate. Due to its low weight and high impact resistance, polycarbonate is the dominant material for making automotive headlamp lenses. However, automotive headlamps require outer surface coatings because of its low scratch resistance and susceptibility to ultra violet degradation (yellowing). The use of polycarbonate in automotive applications is limited to low stress applications. Stress from fasteners, plastic welding and molding render polycarbonate susceptible to stress corrosion cracking when it comes in contact with certain accelerants such as salt water and plastisol. It can be laminated to make bullet-proof "glass", although "bullet-resistant" is more accurate for the thinner windows, such as are used in bullet-resistant windows in automobiles. The thicker barriers of transparent plastic used in teller's windows and barriers in banks are also polycarbonate.

So-called "theft-proof" large plastic packaging for smaller items, which cannot be opened by hand, is uniformly made from polycarbonate.

Lockheed Martin F-22 cockpit canopy

The cockpit canopy of the Lockheed Martin F-22 Raptor jet fighter is made from a piece of high optical quality polycarbonate, and is the largest piece of its type formed in the world.[11][12]

4.5 Niche applications

Polycarbonate, being a versatile material with attractive processing and physical properties, has attracted myriad smaller applications. The use of injection molded drinking bottles, glasses and food containers is common, but the use of BPA in the manufacture of polycarbonate has stirred serious controversy (see Potential hazards in food contact applications), leading to development and use of "BPA-free" plastics in various formulations.

Laboratory safety goggles

Polycarbonate is commonly used in eye protection, as well as in other projectile-resistant viewing and lighting applications that would normally indicate the use of glass, but require much higher impact-resistance. Polycarbonate lenses also protect the eye from UV light. Many kinds of lenses are manufactured from polycarbonate, including automotive headlamp lenses, lighting lenses, sunglass/eyeglass lenses, swimming goggles and SCUBA masks, and safety glasses/goggles/visors including visors in sporting helmets/masks, and police riot gear (helmet visors, riotshields, etc.). Windscreens in small motorized vehicles are commonly made of polycarbonate, such as for motorcycles, ATVs, golf carts, and small planes and helicopters.

The light weight of polycarbonate as opposed to glass has led to development of electronic display screens that replace glass with polycarbonate, for use in mobile and portable devices. Such displays include newer e-ink and some LCD screens, though CRT, plasma screen and other LCD technologies generally still require glass for its higher melting temperature and its ability to be etched in finer detail.

As more and more governments are restricting the use of glass in pubs and clubs due to the increased incidence of glassings, polycarbonate glasses are becoming popular for serving alcohol because of their strength, durability, and glass-like feel.[13][14]

Other miscellaneous items include durable, lightweight luggage, MP3/digital audio player cases, ocarinas, computer cases, riot shields, instrument panels, tealight candle containers and blender jars. Many toys and hobby items are made from polycarbonate parts, e.g. fins, gyro mounts, and flybar locks for use with radio-controlled helicopters.[15]

Standard Polycarbonate resins are not suitable for long term exposure to UV radiation. To overcome this the primary resin can have UV Stabilisers added. These grades are sold as UV Stabilised Polycarbonate to Injection Moulding and Extrusion companies. Other applications including Polycarbonate sheet may have the anti-UV layer added as a special coating or a coextrusion for enhanced weathering resistance.

Polycarbonate is also used as a printing substrate for nameplate and other forms of industrial grade under printed products. The polycarbonate provides a barrier to wear, the elements, and fading.

4.5.1 Medical applications

Many polycarbonate grades are used in medical applications and comply with both ISO 10993-1 and USP Class VI standards (occasionally referred to as PC-ISO). Class VI is the most stringent of the six USP ratings. These grades can be sterilized using steam at 120 °C, gamma radiation, or by the ethylene oxide (EtO) method.[16] However, scientific research indicates possible problems with biocompatibility. Dow Chemical strictly limits all its plastics with regard to medical applications.[17][18]

4.6 Phones

Some major smartphone manufacturers use polycarbonate. Nokia has used polycarbonate in their phones starting with the N9's unibody case in 2011. This practice continues with various phones in the Lumia series. Samsung has started using polycarbonate with Galaxy S III's battery cover in 2012. This practice continues with various phones in the Galaxy series. Apple has started using polycarbonate with iPhone 5c's unibody case in 2013.

5 Primary resin manufacturers and brands

6 Semi-finished products produced from polycarbonate

7 History

Polycarbonates were first discovered in 1898 by Alfred Einhorn, a German scientist working at the University of Munich.[19] However, after 30 years of laboratory research, this class of materials was abandoned without commercialization. Research resumed in 1953, when Hermann Schnell at Bayer in Uerdingen, Germany patented the first linear polycarbonate. The brand name “Makrolon” was registered in 1955.[20]

Also in 1953, and one week after the invention at Bayer, Daniel Fox at General Electric in Schenectady, New York, independently synthesized a branched polycarbonate. Both companies filed for U.S. patents in 1955, and agreed that the company lacking priority would be granted a license to the technology.[21][22]

Once patent priority was resolved, in Bayer’s favor, Bayer began commercial production under the trade name Makrolon in 1958 and GE began production under the name Lexan in 1960.

After 1970, the brownish original polycarbonate tint was improved to “glass-clear.”

8 Potential hazards in food contact applications

Main articles: Bisphenol A and Endocrine disruptor

The use of polycarbonate containers for the purpose of food storage is controversial. The basis of this controversy is their hydrolysis (degradation by water, often referred to as leaching) occurring at high temperature, releases bisphenol A:

$$1/n\ [OC(OC_6H_4)_2CMe_2]_n + H_2O \rightarrow (HOC_6H_4)_2CMe_2 + CO_2$$

More than 100 studies have explored the bioactivity of bisphenol A derived from polycarbonates. Bisphenol A appeared to be released from polycarbonate animal cages into water at room temperature and it may have been responsible for enlargement of the reproductive organs of female mice.[23] However, the animal cages used in the research were fabricated from industrial grade polycarbonate, rather than FDA food grade polycarbonate.

An analysis of the literature on bisphenol A leachate low-dose effects by vom Saal and Hughes published in August 2005 seems to have found a suggestive correlation between the source of funding and the conclusion drawn. Industry-funded studies tend to find no significant effects whereas government-funded studies tend to find significant effects.[24]

Sodium hypochlorite bleach and other alkali cleaners catalyze the release of the bisphenol A from polycarbonate containers.[25][26] A chemical compatibility chart shows that polycarbonate is incompatible with ammonia and acetone because it dissolves in their presence.[27] Alcohol is one recommended organic solvent for cleaning grease and oils from polycarbonate.

9 Effect of fungi

In 2001 a species of fungus in Belize, *Geotrichum candidum*, was found to consume the polycarbonate found in compact discs (CD).[28] This has prospects for bioremediation.

10 See also

- CR-39, allyl diglycol carbonate (ADC) used for eyeglasses
- Organic electronics
- Mobile phone accessories
- Thermoplastic polyurethane
- Vapor polishing

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12 External links

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