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HOW TO USE THE MODERN PLASTICS ENCYCLOPEDIA

The Encyclopedia is organized into four basic sections, each planned to serve a different need:

1 For broad and general information about materials and processes, The Textbook (pp. 4-477) : What is high density polyethylene? How do antioxidants work? What is stretch-blow molding? These are the types of questions the Textbook is designed to answer.

The Textbook contains 169 articles that provide information in the areas of Materials, including resins, foams, films, sheeting, alloys; Composites, including laminates and reinforced materials; Chemicals, additives, fillers, property enhancers, and reinforcements; Primary processing, including testing, tooling, and auxiliary equipment; and Fabricating and finishing. Arrangement of articles is in alphabetical sequence by subject within each category. See listing of Contents, p. 2.

2 For systematic guidelines to the meaningful use of plastics properties in material selection, The Design Guide (pp. 479-512) : What are the key steps in choosing a polymer for a plastics application? What is the meaning of "creep strength" and how can this property be related to my design requirements? What are the effects of elevated temperature exposure on electrical properties, for example, or on chemical resistance? These are the types of questions the Design Guide is designed to answer.

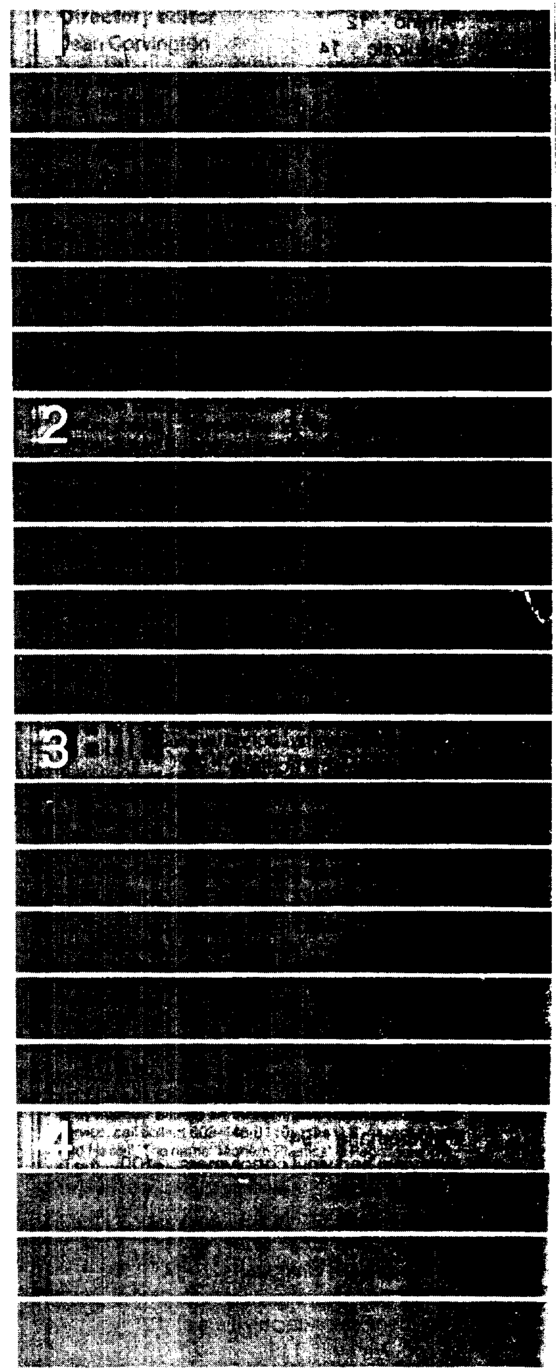
The Design Guide provides the conceptual background and the practical considerations involved in making a product that works, and in making it at the lowest cost. Designing products for rigidity and strength under load and selecting materials for elevated temperature performance and for chemical, impact, and fatigue resistance are covered. Other sections describe proper use of creep data and the torsion pendulum test. See the Design Guide Contents, p. 479.

3 For precise design and specification data on materials and equipment, The Engineering Data Bank (pp. 513-824) : What specific material will meet my service temperature requirements of 200°F. continuous? Is there a transparent plastic that can be used in a mildly alkaline environment? What material would meet Underwriters Laboratories' V-0 rating and also have good weatherability? What types and sizes of RIM equipment are available? These are the types of questions the Engineering Data Bank is designed to answer.

The Engineering Data Bank provides detailed information on properties and characteristics of specific plastics materials, chemicals for plastics, and processing machinery arranged in tabular form, with most products keyed to individual suppliers and trade designations. Lists also are keyed to advertisements containing additional product information. The Machinery specifier gives detailed specifications on more than 4200 machines. See the Engineering Data Bank Contents, p. 513.

4 To reach individual suppliers of products and services, The Directory of Suppliers (pp. 825-938) : Looking to locate . . . Someone who sells high density polyethylene in powdered form? Complete extrusion-blow molding systems? Is in your area and can custom injection mold a thermoplastic part? These are the types of questions the Directory of Suppliers is designed to answer.

The Directory of Suppliers lists products and services for more than 4800 companies. Complete addresses, including phone numbers when possible, are given for each company. Boldface listings are keyed to advertisements which offer additional product and services information. See the Directory of Suppliers Classified Index, p. 826.



TEXTBOOK

MODERN PLASTICS ENCYCLOPEDIA

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Flammability data and numerical flame spread ratings presented in the Encyclopedia are not intended to reflect hazards presented by the materials under actual fire conditions.

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condition is 3 to 4 hr. at 250°F. Up to 25% of dried regrind can be mixed with virgin material without a significant loss of performance or appearance. However, regrind utilization may produce some effects on color.

Recommended melt temperatures for PBT are between 440 to 530°F. Long residence times and melt temperature in excess of 530°F. should be avoided. PBT's crystalline characteristic allows a wide range of mold temperature between 60 and 250°F., without significant effects on physical properties. The usual range for unreinforced materials is from 100 to 140°F. to give a very smooth and glossy surface. The surface appearance of reinforced grades can be optimized by the use of fast fill rates and high injection pressures. Mold temperatures in excess of 150°F. can change the color of parts made with pigmented grades.

Although PBT is most often injection molded, other processing options include structural foam molding and extrusion. PBT extrusions include profile, film, sheet, and filament. Several modified grades with high melt strength can be blow molded and thermoformed. Secondary operations and finishing methods include adhesive bonding, ultrasonic welding, printing, painting, hot stamping, and vacuum metallizing.

Applications

PBT is being used extensively in automotive, electrical/electronics, appliances, material handling, military, telecommunications, and consumer products. Several grades comply with FDA regulations.

Automotive applications include exterior body parts such as grilles, body panels, fenders, bumpers, wheel covers, and components for doors, windows, and mirrors. PBTs also find use in such under-the-hood applications as distributor caps, rotors, and ignition components. Other automotive uses include headlamp system parts, windshield wiper assemblies, and water pump and brake system parts.

Applications in the electrical and electronic markets are switches, relays, motor housings, fuse cases, key caps for computer key boards, chip carriers, and connectors—especially for wave soldering and with longer, thinner-walled designs. Telephone interface components, junction boxes, and fiber optic buffer tubings are a few examples of new applications in telecommunication areas.

In materials handling markets, PBT grades find use in monorail conveyor components, collapsible auto-part racks, and engine pallets.

The use of PBTs in household applications include iron handles, toaster side panels, vacuum cleaner parts, hair dryer housings, and coffee makers.

Consumer products such as propellers for outboard motors, lawn mower housings, diver propulsion vehicle housing, bicycle gears, protective headgears, shades and housing for lamps, and power tool housings are often molded of PBT-based materials.

Polyethylene terephthalate: PET

By P.L. Heater

Polyethylene terephthalate is a very useful, tough, versatile thermoplastic polyester that is produced at a rate of 4.7 billion lb./yr. in the U.S. Its uses range from tire cord reinforcement to beverage bottles to food trays for microwave and conventional ovens.

Chemistry and properties

PET is prepared from ethylene glycol (EG) and either terephthalic acid (TPA) or the dimethyl ester of terephthalic acid (DMT) and has the formulation shown in Fig. 1.

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EG is prepared using ethane as feedstock; TPA is manufactured using p-xylene as feedstock. This can be followed by an esterification with methanol to prepare DMT.

PET exists in an amorphous state (non-crystalline), an oriented and partially crystalline state, and a highly crystalline state. Most applications require orientation and/or crystallization in order to take advantage of the dramatically increased strength and improved serviceability at high temperatures that result. The amorphous polymer exhibits a glass transition temperature of about 74°C., and the crystalline melting point ranges from about 255 to over 270°C., depending on the heat history of the sample and the amount of byproduct diethylene glycol present. The polymer crystallizes only in a narrow temperature range, generally from 120 to 220°C., with a maximum rate occurring at about 190°C. Molecular weights for commercially available PET products range from 18,000 to 42,000 (number average), which corresponds to an intrinsic viscosity range of about 0.59 to 1.04 dl./gram. These molecular weights also correspond to a zero shear melt viscosity range of 2143 to 37,000 poise at 280°C.

Orientation of PET produces a very high-strength material. Typical physical properties for oriented PET are:

Tensile strength: 25,000 to 36,000 p.s.i. oriented, 8000 p.s.i. unoriented.

Elongation at break: 12 to 130% depending on the degree of orientation achieved.

Density: 1.33 g./cc. amorphous; 1.37 g./cc. oriented, partially crystalline; 1.45 g./cc. highly crystalline.

Permeability: CO_2, 12 to 20 cc./mil/100 in./day at 73°C., O_2, 5 to 10 cc./mil/100 in./day.

Water vapor transmission: 2 to 4 g./mil/100 in./day at 100°F.

PET polymers are available reinforced with glass fibers, mineral fillers, and/or nucleating agents. These products are designed for molding applications and exhibit improved crystallization rates, impact, and warpage resistance. This class of PET product is covered separately in the article on p. 46.

Processing

PET is made into useful articles by extrusion at high temperatures (270 to 320°C.), coupled with molding, fiber spinning, or film processing. Any processing of PET requires that it be dried to a moisture content of less than 50 p.p.m. water (0.005% by weight) to prevent hydrolysis during processing, which lowers molecular weight. Drying is accomplished at about 150°C., using vacuum driers or hoppers purged with dehumidified air. The drying procedure also crystallizes amorphous PET, which is important for extrusion processing. Conventional extrusion equipment can be used if it is properly sized; barrel cooling may be necessary at high throughputs.

To produce an oriented product, an amorphous form is required. For spinning fibers the amorphous form is an air-cooled

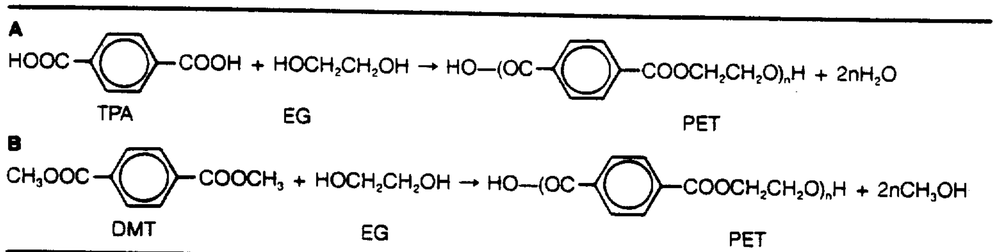

Fig. 1: Chemical structure of PET, using terephthalic acid (A) or dimethyl terephthalate (B) and ethylene glycol as starting materials.

DUPONT

filament, which is subsequently drawn above its glass transition temperature to give an oriented fiber.

For thin-film processing, contact with a water-cooled roll positioned close to the extruder die is necessary. For thicker films or heavy monofilament, cooling in a water bath is necessary to bring the polymer quickly below the Tg. In the subsequent orientation process the polymer is heated above its Tg and stress is applied to orient the polymer chains into an extended alignment with increased molecular order and some crystallinity.

For orientation in one direction, or uniaxial orientation as used for fibers, a draw ratio of 4:1 to 7:1 is used. In biaxial orientation, used for films and bottles, a draw ratio of 1.5:1 to 4:1 is common.

Development of the technology to blow mold amorphous preforms has created the major market for PET in beverage bottles. PET is injection molded in water-cooled molds to produce clear, amorphous preforms. Alternatively, a heavy-walled tube is extruded continuously and cut to appropriate lengths. Either preform is converted to the finished bottle by heating above Tg and blowing into the final mold.

PET has also fit well into the thermal forming process. Instead of cold molds, hot molds are used to produce a crystallized tray product for use in food packaging.

Technology is available to recycle PET into useful non-food-contact applications. PET beverage bottles, for example, are ground and separated from the paper labels, metal caps, and PE base caps via air and water separation techniques to produce a PET flake which is pure enough for use in non-food-contact applications, such as strapping, staple fiber for pillow and sleeping bag filler, and floor tiles.

Applications

Since PET is a pure and regulated material meeting FDA food-contact requirements, it is widely used in food packaging. Two of its largest applications are beverage bottles and dual-ovenable food trays. The orientation of PET in a beverage bottle sidewall produces a bottle that is shatterproof and creep-resistant, and that acts as a very good barrier to gas and water transmission. Also, the two-liter bottle weighs about 1/13th as much as the same-size glass bottle. This produces savings in energy consumption and transportation costs throughout the beverage delivery system. PET has captured virtually all of the two-liter non-returnable beverage market and is doing well in the half-liter, one-liter, and three-liter markets.

PET bottles are used for a wide variety of foods and beverages, including wines, beer, liquor, salad dressing, mouthwash, edible oil, syrups, mustard, peanut butter, nuts, and pickled foods. Containers for toiletries, cosmetics, and household and pharmaceutical products also are being used. Toothpaste pumps are a recent example in this area.

Dual-ovenable trays made from PET are used primarily for frozen foods that can be heated in a microwave or conventional oven. The trays are made from amorphous PET sheet which is thermoformed into trays and crystallized to give high-temperature service. These trays are also marketed as retail cookware, and for food service use. In addition, paperboard and molded pulp trays coated with PET are widely used for food applications.

Other applications include molding resins, X-ray and other photographic films, magnetic tape, electrical insulation, printing sheets, and film for food packaging, including boil-in-bag pouches and processed meat packaging.

Reinforced PET

By P.G. Galanty, C.A. Ball, and G. Arnesen

Reinforced PET products are thermoplastic polyesters based on polyethylene terephthalate. They are closely related in terms of chemistry, properties, and areas of application to reinforced polybutylene terephthalate (PBT) compounds. The key distinguishing features of reinforced PET from similar PBT materials are higher strength properties, higher use temperature, and generally lower cost. Injection molding is the principal fabrication technique. Major application areas are automotive structural components and electrical/electronic parts.

Chemistry and properties

The slow crystallization rate of PET and the relatively high temperature at which crystallization must be accomplished have historically precluded PET from occupying a competitive position in the world of high-performance engineering plastics. In recent years proprietary modifier packages containing plasticizers and other chemicals have been developed that solve this problem. Today, reinforced PET products can be injection molded at mold temperatures of 180 to 220°F. with cycle times comparable to similar PBT and nylon grades.

Reinforced PET products are generally produced by a standard compounding operation in which glass fibers, minerals, modifiers, flame retardants, etc. are added to achieve the desired combination of properties. A medium viscosity PET, similar to the type used in producing beverage containers, can be used as the base resin. PET enjoys an inherent cost advantage over PBT that is attributable to lower cost raw materials (ethylene glycol vs. butane diol) and the substantially higher volume produced for containers, films, and fibers. A further cost advantage may be realized when the technology for recycling PET containers, film, etc. advances to a level at which a feedstock suitable for use in engineering plastics becomes available.

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The properties of RPET are similar to those of RPBT and dry nylon-6 and -6/6. The tensile strength of RPET is higher than that of RPBT (22,000 vs. 17,000 p.s.i., for 30% glass-filled grades). RPET absorbs less moisture than nylon-6/6 (0.05% vs. 0.70% in 24 hr., for 30% glass-filled grades). But nylons offer higher impact resistance (2.20 vs. 1.80 ft.-lb./in. notched Izod for 30% glass-filled nylon vs. RPET). The electrical and chemical resistance of RPET and RPBT are comparable.

Grades

Numerous grades are available. Part stiffness can be varied by changing glass content, usually over the range of 15 to 50%. Maximum isotropic shrinkage or minimum warpage can be achieved in structures having complex geometries by incorporating low aspect ratio fillers, such as minerals, in the reinforcing mix. Impact-modified formulations are available for applications requiring significantly higher shock resistance. Foamed parts have also been molded. (Selection of a foaming agent, however, should be made only after consultation with the resin supplier.) UL-94 flammability ratings of V-0 in 1/32-in. thickness can be achieved with the addition of a flame retardant system. These grades also feature UL thermal index ratings of up to 155°C. in all categories, at thicknesses down to 1/32 inch.

Processing

RPET must be predried in dehumidified air to ≤0.01% moisture. A typical procedure would be to use 250°F., −15°F. dew point air circulating at 1 cu.ft./min./lb. RPET processed/hr. Because moisture regain is relatively low, these conditions are also recommended when processing resin and regrind (10 to 15%) having long-term ambient exposure.

Melt temperatures can range from 530 to 590°F. Melt viscosity will be proportional to melt temperature. The relatively broad operating range, therefore, provides the potential for making adjustments when there are significant changes in melt flow demands. Mold temperatures of 180 to 220°F. are normally maintained. Surface appearance improves with increasing mold temperatures. Part crystallinity is also a function of mold temperature, but since the thermal conductivity of RPET is relatively low, the trend diminishes rapidly with increasing wall thickness.

Shot size as a percentage of barrel capacity depends on several factors. A typical recommendation would be 30 to 70%. Exceptions, however, can be made via judicious selection of melt temperature, screw speed, and cycle time.

Applications

RPET has earned acceptance in applications extending from small multicavity electrical/electronic to large structural industrial parts. Current major applications include automotive and office furniture components requiring a high level of stiffness over a wide humidity range. Other