Compounding Recycled PET

Issue: *Although PET has an excellent balance of performance properties, there are some shortcomings that have prevented large scale use of recycled PET in injection-molded, durable products. The primary drawbacks are PET's low glass transition temperature, the slow crystallization rate of copolymer grades of PET, and relatively low impact strength. The properties of recycled PET must be modified for use in durable products, such as appliances, electronics, furniture, transportation, and building and construction. Compounding of recycled PET can correct these shortcomings, enhance other properties, and tailor performance properties to meet specifications.*

Background: Durable products are exposed to rigorous and varied environments. Therefore, the resins used to manufacture durables must have superior mechanical, thermal, electrical, chemical, and environmental properties to packaging resins. These so-called engineering resins possess a balance of properties tailored to each durable application. In many cases, this tailoring is accomplished by compounding. This is especially true for post-consumer PET.

An example of rigorous environmental conditions is the continuous service temperature, which, for many durable products, is much higher than 175°F. The glass transition temperature at which unmodified bottle-grade PET resin begins to soften and become rubbery is at 165ºF to 175°F. Therefore, the direct use (without specific additives) of recycled PET in these products is not feasible.

<u>PET Structure</u>. PET is one of a few plastics whose molecular structure in a finished part can be amorphous, crystalline, or semi-crystalline (somewhere in between.) Amorphous PET tends to be easier to process, tougher, more flexible, and clearer than crystalline PET, if all else is equal. Crystallinity is desirable in products that require high temperature stability, dimensional stability, stiffness, tensile strength, and barrier properties. The majority of bottle-grade PET being recycled today is a copolymer and, therefore, is inherently slow to crystallize. The best balance of properties is usually some combination of these two structures.

Crystalline PET is best suited for manufacturing processes where its crystallinity is enhanced by mechanical orientation. Products manufactured this way include fibers, strapping, film, oriented sheet and stretch blow molded bottles. Crystallinity in PET products is controlled by orientation, cooling rate, and/or nucleation. In each case, the formation of strain-induced crystals is precisely controlled to develop certain targeted properties in the finished product.

Best Practices: When molding PET compounds into durable applications, the first step is to work closely with the customer and develop a comprehensive list of performance requirements for the product. A technical review of these performance specifications should be completed to determine if recycled PET, with modification, could cost-effectively meet the customer's requirements.

The next step is to establish a partnership with an independent, experienced PET compounder or a resin company. The key requirement is experience, because the semi-crystalline nature of PET sets it apart from many other engineering resins. Successful injection molding of post-consumer PET is dependent on a full understanding of the complex relationships between molding conditions and the resin formulation. There is both art and science involved and the learning curves for each are quite steep.

In addition to experience, the ideal partner should be capable of compounding different formulations and injection mold parts on a small scale for evaluation and testing. Each product will require some formulation development because of the limited use, to date, of recycled or virgin PET in injection molding. There are only a few tried and tested PET compounds, and each is proprietary.

The third step is to develop two or three compounded formulations for trial on commercial molding equipment. Each formulation should tailor the resin properties to a "best-fit" of those specified by the customer. The need for variations of the formulation is to adjust for differences in molding machines, especially for cooling rates and process controls.

Although highly complex and sensitive to interactions between ingredients, a typical recipe for a durable product can include some or all the following ingredients:

- Glass or other fibers to provide stiffness, strength, and/or electrical properties
- Nucleator to control the level of crystallinity
- Impact modifiers to impart toughness
- Flame retardant additives to meet product safety requirements
- Mineral fillers to stiffen, provide dimensional stability and/or reduce cost
- Heat and/or light stabilizers
- Lubricants for improved processing
- Antistats to minimize the development of static charge
- Liquid color or color concentrate

Once an acceptable formulation is proven for a given application, an additional best practice is to fully characterize the post-consumer PET used. This establishes baseline data from which detailed material specifications can be developed. It is important to precisely control raw material quality because slight variations in Intrinsic Viscosity or contaminant levels will change PET properties or crystallization rate. Stringent incoming quality controls will help ensure that molded products have consistent properties.

An important best practice is to thoroughly dry the PET blend formulation (e.g., to 100 ppm moisture or less, *per PET Drying Best Practice*) just prior to compounding to avoid hydrolysis of PET and subsequent loss of molecular weight and properties. Dryness should be maintained until compounding begins.

The appropriate, dried formulation is then homogenized, melt filtered, and pelletized in an extruder. Single-screw extruders with screw length/diameter ratios of 20-24:1 are generally acceptable and preferred for the incorporation of several ingredients at concentrations of a few percent each. For relatively high loadings of ingredients or glass filling, a twin screw extruder is preferred.

Controlling crystallinity. The formation of strain-induced crystals must be precisely controlled to develop certain targeted properties in the finished product. Crystallinity can be controlled through mechanical orientation, nucleation, or by controlling the cooling rate. (*Also Refer to the Drying/Moisture Control Best Practice).*

Rapid cooling, such as in molding of PET bottle preforms, minimizes the formation of crystals. Slow cooling has the opposite effect allowing crystals to form. In addition, slow cooling results in lengthy cycle times and undesirable coarse crystals. Heat-induced crystals are coarser than strain-induced crystals and can reduce clarity or impart brittleness.

Nucleation is used when orientation and slow cooling are not practical options. This is certainly the case in injection molding, where the process is not suited for controlled mechanical orientation. Small percentages of inorganic minerals, organic compounds, or melt-compatible crystalline resins are used to control crystallinity in injection-molded PET parts.

Implementation: Work closely with resin suppliers, customers and compounders to ensure the final products meet all specifications and performance requirements.

Benefits: Proper blending ensures a homogeneous mixture, which prevents variations in the processibility of the melted resin, which can cause high scrap rates and inferior end-products. The durable goods industry represents a large, relatively untapped, market for recycled PET.

Contact: For more information about this Best Practice, contact CWC at (206) 443-7746 or e-mail at info@cwc.org.

Issue Date / Update: January 1998