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Comprehensive Guide on Polyethylene Terephthalate (PET)

Polyethylene terephthalate (PET) is an aliphatic polyester. It has a semi-crystalline form when stable. It is used in everyday items and easily recyclable. It finds use in packaging, textiles, films to molded parts for automotive, electronics. It shows resistance to impact, moisture, alcohols and solvents.

Polyethylene terephthalate or PET belongs to the family of polyesters. It is widely used in everyday items and easily recyclable. It has a semi-crystalline form when stable. Most common application include rigid and flexible packaging as it is very light weight.

PET is among those plastics which are an important part of your everyday life. You find the polymer used in packaging, fabrics, films to molded parts for automotive, electronics and many more. For all the applications demanding lightweight and impact-resistant material, PET is of your choice. Also do not forget, PET is one of the most recycled thermoplastics as well.

Additionally, there have been continuous efforts to tailor PET properties for improved performance with beneficial cost profiles to meet high-end application demands.

At the same time, polypropylene, polyethylene and polyvinyl chloride are equally popular for these benefits, so how do you find which one is suited for you? In this guide, you will find out the key knowledge to find the suitable grade among thousands of options available.

Hi, In search of sustainable materials for your project?

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Overview

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- Which is a suitable packaging material - HDPE or PET?
- PET vs PVC
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- PET Films vs BOPP Films
- What are the commercially available PET grades

Key Applications

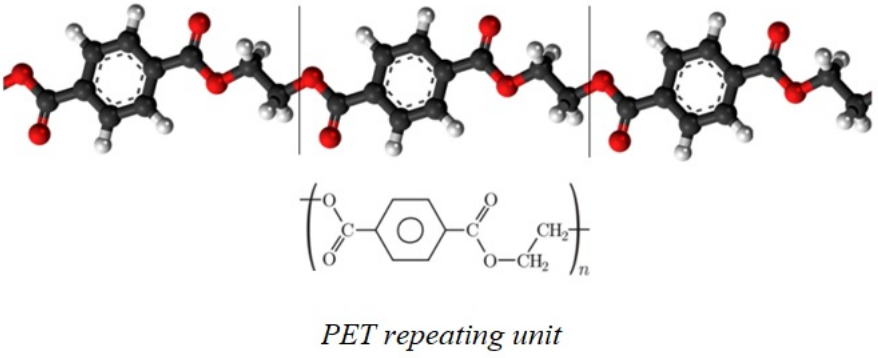
Key Properties

Suppliers

Brands

What is polyethylene terephthalate?

Polyethylene terephthalate (PET or PETE) is a general-purpose linear semicrystalline thermoplastic polymer. It belongs to the polyester family of polymers. These resins are known for their excellent combination of properties. These properties include mechanical, thermal, and chemical resistance as well as dimensional stability. Its chemical formula is $(C_{10}H_8O_4)_n$.

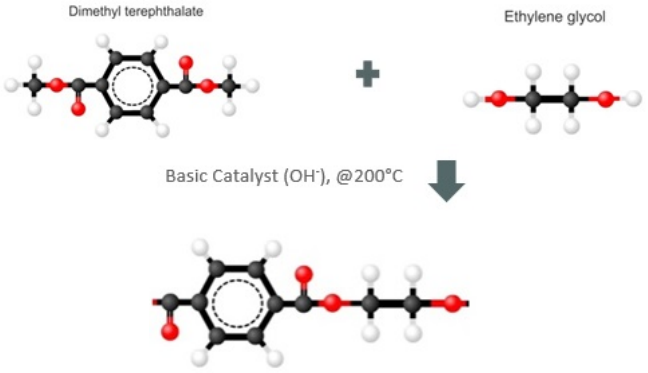


Molecular Structure of Polyethylene Terephthalate

How polyethylene terephthalate is made?

Polyethylene terephthalate is an aliphatic polyester. It is obtained from the polycondensation reaction of the monomers obtained either by:

- Esterification reaction between terephthalic acid and ethylene glycol, or
- Trans-esterification reaction between ethylene glycol and dimethyl terephthalate



The reaction produces PET in the form of a molten and viscous mass. This can be directly spun into fibers or extruded or molded into almost any shape. Chemically, Polyethylene terephthalate is very much similar to Polybutylene Terephthalate.

What properties assist in PET selection?

Polyethylene terephthalate is highly flexible, colorless and semi-crystalline resin in its natural state. Depending upon how it is processed, it can be semi-rigid to rigid. It shows good dimensional stability, resistance to impact, moisture, alcohols and solvents.

Key features include:

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- Higher strength, heat distortion temperature (HDT) and stiffness than PBT
- Very strong and lightweight & hence easy and efficient to transport
- Good gas (oxygen, carbon dioxide) and moisture barrier properties
- Excellent electrical insulating properties
- Broad range of use temperature, from -60 to 130°C
- Low gas permeability, particularly with carbon dioxide
- Suitable for transparent applications, when quenching during processing
- It doesn't break or fracture. It is practically shatter-resistant and hence, a suitable glass-replacement in some applications.
- It is recyclable and transparent to microwave radiation.
- It is approved as safe for contact with foods and beverages by the FDA, Health Canada, EFSA & other health agencies. Food contact approved PET grades »
- Chemical properties
  - Excellent resistance to alcohols, aliphatic hydrocarbons, oils, grease and diluted acids
  - Moderate resistance to diluted alkalis, aromatic & halogenated hydrocarbons

The glass transition temperature of PET varies depending on the degree of crystallinity. It has a Tg of 65-80°C. It has a melting temperature of 240-270°C. Amorphous PET has a Tg of 65°C. The Tg increases with an increasing degree of crystallinity.

Crystallization occurs with a maximum crystallization rate of 178°C at:

- the temperature range of 10°C above its Tg, and
- up to 10°C below its melting temperature.

It normally reaches a crystallinity of 40-50%. It can also be polymerized to a co-polymer that cannot crystallize.

Access several optimized PET grades to find the best suited option for your application:

- Glass fiber-reinforced
- Heat stabilized
- High impact resistance
- High strength
- Flame retardant

The addition of fillers improves impact strength, surface finish, and several other benefits. It also reduces warpage. Some filler examples include glass fibers, CNTs, etc.

What are the limitations of PET?

PET has immensely added to our daily life, but there still exist some drawbacks with the polymer.

The crystallized form of PET has:

- lower impact strength
- lower moldability

These properties are lower in comparison to PBT, due its slow crystallization rate.

Furthermore, PET in amorphous form is easily affected by boiling water, alkalis and strong bases. At high temperatures (>60°C), it can easily be attacked by ketones, aromatic and chlorinated hydrocarbons and diluted acids and bases.

A lot of plastic parts are molded in crystalline PET polyester to make PET capable of handling:

- aggressive chemical environments as well as
- elevated temperatures

Additionally, crystalline PET sometimes requires additives such as nucleating agents and solid particles of fillers and reinforcements. This makes it capable of applications beyond packaging.

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What is PETG?

PET-G stands for Glycol modified polyethylene terephthalate. It is the copolymer form of polyethylene terephthalate homopolymer.

Features of glycol modification of PET through copolymerization include:

- It improves processability (faster elongation rates and higher elongations).
- It lowers the glass transition and melting temperature of PET.
- It decreases the crystallization temperature and rate.
- It is a polyester with good toughness and chemical resistance.
- It also differentiates the properties of polyethylene terephthalate (PET).

As a technical material, PETG provides good mechanical properties. It also improves chemical and thermal behaviors with similar ease of use. All these comparisons are made with respect to PLA.

The common modifiers which replace ethylene glycol or terephthalic acid to produce PETG are cyclohexane dimethanol (CHDM) and isophthalic acid respectively. These modifiers interfere with crystallization and lower the polymer's melting temperature.



How is PET processed?

Polyethylene terephthalate can be easily processed by injection molding and extrusion. It is generally extruded to produce films and sheets and can be later thermoformed. Blow molding is generally used to produce transparent bottles.

Recommended drying time is 2-4 hours at 120°C before processing. Up to 25% regrind can be used.

Blow Molding

The blow molding process works by reheating a pre-molded PET preform. It is then automatically positioned into a mound.

Extrusion- and stretch blow molding can be used to fabricate polypropylene bottles. They are used for packaging products such as:

• Ketchup and sauces • Cleaning products • Mineral water • Food and beverages	• Water • Pharmaceuticals • Dried foods and spices • Household cleaners • Isotonic and sports drinks • Baby formulas • Housewares • Liquid soaps and detergents

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PET Bottle Preform for Blow Molding

Injection Molding

PET injection molding is one of the very important technologies for plastic processing. Since it is a hygroscopic material, it must be dried to a moisture content of 0.05% or less. This allows it to create a non-crystalline transparent preform.

If the moisture content is too high, the PET molecular chains can thermally decompose. This reduces the physical and mechanical properties as well as the crystallization rate. This thereby impacts the quality of the product.

This polyester is a heat-sensitive material with a narrow forming temperature. During the process, if the temperature is:

- **Too low** – It is not good to make plastic parts. Depression and lack of material defects can occur.
- **Too high** – It can cause a spill, nozzle salivation, and deep color change. It can also decrease mechanical strength and cause degradation.

1. Barrel temperature (unreinforced grades): 240~280°C
2. Barrel temperature of glass fiber reinforced PET: 250~290°C
3. Nozzle temperature: Should not exceed 300°CC
4. Melt temperature: 280-310°C
5. Mold temperature: 140-160°C to obtain a crystalline PET (for technical applications)
6. Screw with an L/D ratio of 18-22 is recommended
7. For transparent applications, mold temperature should lie between 10 and 50°C

Extrusion

Polyethylene terephthalate is generally extruded to produce films and sheets. After extrusion, they can be thermoformed for food packaging applications. Its extrusion temperature ranges between 270-290°C.

3D Printing

PET and PETG filaments are known to produce 3D Printed objects. These filaments have high flexibility and toughness. PETG filament is easier to print than ABS. It offers:

- higher strength,
- lower shrinkage, and
- smoother finish.

The material also benefits from great thermal characteristics. This allows the plastic to cool efficiently with almost negligible warpage.

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1. Recommended hot end temperature: 240 and 260°C
2. Bed temperature: 100°C
3. Retraction speed slow at 30mm/s or less

PET packaging accounts for more than 50 percent of total plastic waste. This extends its lifetime by reusing it as feedstock. This in turn offers a broadly available alternative to virgin raw materials. More recycled PET filaments are developed to produce unique designs and new products.

Explore some PET grades apt for 3D Printing/Additive Manufacturing in our database.

What happens when PET blends with other polymers?

Polyethylene terephthalate blends with thermoplastics or thermosets to tailor new materials. Blending materials have improved performance with beneficial cost profiles. It opens up the potential for new markets without much investment and development.

The following thermoplastics, thermosets and rubbers are used to produce blends with PET.

◦ Polyethylene ◦ Polypropylene ◦ Polycarbonate ◦ Acrylonitrile Butadiene Styrene ◦ Polystyrene ◦ Ethyl vinyl acetate ◦ Polyester	◦ Epoxy resins ◦ Phenolic resins	◦ Styrene butadiene rubber ◦ Nitrile butadiene rubber

- PET modified with polyolefins are often glass fiber reinforced. They are used in injection-molded automotive and industrial applications.
- Applications with PET/PC blends require a combination of properties such as:
  - excellent toughness, chemical and heat resistance
  - along with high impact, tensile and flexural strength
- Blending PET with PBT offers a great influence on mechanical properties like impact strength. These blends combine the fast crystallization rate of PBT with the low cost of PET.
- Blending thermosets with PET improves thermal, mechanical, impact resistance, and flame-retardant properties. Used for the production of automotive, aeronautic, and electronic components.

The main objective of developing these blends is to improve cost-effectiveness, mechanical strength, flame retardancy, toughness, processability, etc.

Is PET recyclable?

Polyethylene Terephthalate is 100% recyclable. It is the most recycled plastic worldwide. It can be easily identified by its recycling code #1.



How rPET is processed?

It offers significant advantages (weight, durability, versatility) compared to alternative materials. This makes it a widely used polymer in the packaging and textile sectors. This class of polyesters has a short lifespan. Hence, almost all products marketed are transformed into waste. This makes it a priority target for recycling. A low diffusion coefficient makes it more suitable as a recovered, recycled material.

Post-consumer PET bottles are collected and processed:

- through a series of special washing processes or
- by chemical treatment

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This breaks down PET into its raw materials or intermediates. They are further used to produce recycled PET (rPET) flakes. The growth of bottle recycling facilitates the development of processing technologies. This increases product purity and reduces operational costs.



PET Recycling Facility

What are the methods to recycle PET?

The most adopted methods for PET recycling are:

1. **Chemical recycling by hydrolysis**: This method involves the production of terephthalic acid (TPA) and ethylene glycol (EG). Reutilizing them for making other synthetic chemicals.
2. **Mechanical recycling**: Cost-effectiveness and environmental friendliness make mechanical recycling the most common PET recovery method.



Recycling and reprocessing cause a decrease in melt viscosity and average molecular weight. This can negatively affect the final product's tensile and impact strength.

How to upgrade recycled PET bottles?

Bottle-grade rPET is upgraded into engineering-grade PET for injection molding. rPET is used as a matrix for composites based on glass fiber-reinforced virgin PET. This is a cost-effective and environmentally friendly way.

Applications of rPET

As with virgin PET, recycled PET or rPET flakes are used in several applications such as:

- Fiber for carpet, fleece jackets, comforter fill, and tote bags
- Containers for food, beverages (bottles), and non-food items
- Automotive parts (carpets, sound insulation, boot linings, seat covers)
- Film and sheet
- Strapping, and
- Industrial end-use items (geotextiles and roof insulation)

rPEt can also be blended in a ratio of virgin to recycled, depending on the application required.

Explore various PET grades with Post Consumer Recycled Content »

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Is PET toxic?

Heat treatment of recycled PET flakes removes any volatiles making them safe. They meet the requirements to be safe for direct food contact.

According to the ILIS study:

- PET itself is biologically inert if ingested.
- It is dermally safe during handling.
- It is not a hazard if inhaled.
- No evidence of toxicity has been detected in feeding studies using animals.

Negative results from Ames tests and studies into unscheduled DNA synthesis indicate that PET is not genotoxic. Similar studies conducted with monomers and typical PET intermediates also indicate that these materials are non-toxic. They pose no threats to human health.

Also, PET bottles and containers that find their way to the landfill pose no risk of harm or leaching. Since the polymer is inert, it is resistant to microbial attack and won't biologically degrade. PET bottles can also easily be crushed flat and hence, takes up relatively little landfill space.

Which class of polyester to choose?

Polyethylene terephthalate (PET) and polybutylene terephthalate (PBT) both belong to the polyester family. The use of alcohol resulting in an ester group makes these polymers distinctive.

In chemical composition, PBT differs only slightly from PET. PBT has a higher crystallization rate and lower melting point. PET can be either semi-crystalline state or amorphous. It is impossible to produce amorphous PBT parts under normal processing conditions. PBT crystallizes faster than PET and remains crystalline. In the case of PET, the time used to cool down the polymer decides its amorphous and crystalline behavior.

Compared to PBT, PET has the following features:

- higher strength and rigidity,
- less flexible tougher, and
- lower chemical resistance.

So, if you need to make a plastic component that has better stiffness, toughness, and transparency at room or slightly elevated temperatures (~50°C), then PET is your material of choice over PBT.

HDPE vs PET – Suitable Packaging Material

PET and HDPE have some notable differences. Both these plastics are excellent packaging materials.

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1. **Appearance**: PET is a clear plastic while HDPE is opaque.

2. **Stress cracking**: PET bottles and containers have better resistance. HDPE is highly prone to environmental stress cracking due to its semi-crystalline nature. With higher molecular weight, crystallinity decreases. Thus, the plastic becomes more resistant to environmental stress cracking. Additionally, bottle-grade PET is amorphous and is engineered to prevent crystallization. If it crystallizes, it will lose its transparency as well as show poor impact resistance.

3. **Durable and temperature resistant**: HDPE containers are slightly more durable and temperature resistant. They have a high operating temperature of 160°F compared to 145°F for PET bottles.

4. **Clarity**: Due to this feature PET has natural CO2 barrier properties to maintain food and beverage quality.

5. While HDPE is a cost-effective polymer, PET has a better strength-to-weight ratio. Thus, more products can be delivered with less packaging – less waste. It reduces overall **transportation costs** as well as **carbon footprint**.

6. **Sustainability and recyclability** are becoming key aspects when it comes to material selection. Both HDPE (code – 2) and PET (code – 1) are recyclable. The low diffusion coefficient makes PET much more suitable as a recovered, recycled material. Hence, it continues to remain a sustainable choice for the food and beverage packaging industry.

PET vs PVC

Between PET and PVC, selection solely depends on the function of your part and how you need the finished part to perform.

Among the two polymers, PET has the edge when it comes to recycling. PVC recycling is challenging due to high Cl content of raw PVC (56% by weight). Of all plastics, PVC uses the highest proportion of additives. As a result, PVC requires separation from other plastics before mechanical recycling.

PVC is a rigid plastic which is moderately durable. It can become hard and eventually break down with exposure to sunlight. This is not an ideal material for using in packaging material. PET is much stronger and more durable product and can withstand UV rays and other natural elements. It is resistant to attacks by micro-organisms, is lightweight, easy to transport, and also shatterproof.

When it comes to cost, PVC and PET are closely priced. However, PET contains more oil-based raw materials than PVC and hence its price changes with fluctuations in oil prices. Also, PET scrap has a higher demand, leading to a higher scrap value. Overall, using PET is a cheaper alternative in the long-run.

PET vs Clear Plastics (Acrylic, Polycarbonate)

When it comes to polymer clarity, Polycarbonate and Acrylic polymers are equally popular and compete with PET for certain applications. While PC has the characteristics of good impact resistance and used to manufacture bottles, cans and various forms of containers for packaging beverages but at the same time it has a very poor stress cracking performance. Therefore, if your application has potential where polymer can fail under stress then your decision to choose PET might be meaningful. PET has better mechanical strength and its film strength is three times better than PC.

Also, if your application involves exposure to certain oils and chemicals, then you would prefer to choose PET over PC. PET is chemical resistant to household cleaners, graffiti-resistant, resistant to alcohol and acid, and overall has a greater resistance to a broader range of chemicals than polycarbonate. PC does have chemical resistance, but it is limited, and overall is less desirable for harsh environment use.

At the same time, acrylic does not have the impact strength of either PET or polycarbonate. While PET products are usually food grade but cannot be used if exposed to UV rays. Acrylic is inherently UV resistant with as little as 3% degradation outdoors over a 10-year period.

Looking for UV-stabilized PET grades? Here's the complete list for you »

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Toxicity and Recycling of PET

Usually, PET is a very stable film. It is well suited for applications requiring a strong film with high tensile properties, scuff resistance, and durability. It is stiffer and clearer than BOPP. While PET films have good barrier properties, BOPP films are more prone to absorption of oil and acidic products and become distorted by those substances.

What are the commercially available PET grades?

Find Suitable Polyethylene Terephthalate Grade

The commercial grades of PET are found to be flame retardant, heat resistant, glass reinforced and, and various other engineering materials offering good strength. Further, the fillers are added to enhance the surface finish, reduce warpage, and other benefits in the process.

View a wide range of polyethylene terephthalate (PET) grades available today, analyze technical data of each product, get technical assistance or request samples.

Arnite® A02 307 DSM

Arnite® A02 307 is a low viscosity, food contact polyethylene terephthalate (PET) grade by DSM. It is suitable for processing by extrusion or injection molding... view more

Arnite® A04 900 DSM

What are the main applications of PET?

Polyethylene terephthalate (PET) is a chemically stable polyester, and its use has risen dramatically in the last few decades with a multitude of applications, ranging from food and drink containers to the manufacture of electronic & automotive components and as fibers in clothes.

Amorphous PET is used for the production of bottles and packaging due to its high transparency, which is very similar to that of glass. In other cases, a semi-crystalline state of polymer is used, which has a milky white color and is opaque.

Packaging Industry's Favorite Food Safe PET

High resistance to various environmental factors along with an absence of harmful low molecular weight substances make it widely used in applications where it comes into contact with food (food industry, food packaging, household appliances). Also, it has good oxygen barrier qualities and can be used with oxygen absorbers to store bulk dry foods.

Polyethylene Terephthalate is used in several packaging applications as mentioned below:

- Because Polyethylene Terephthalate is an excellent water and moisture barrier material, plastic bottles made from PET are widely used for mineral water and carbonated soft drinks
- Its high mechanical strength, makes Polyethylene Terephthalate films ideal for use in tape applications
- Non-oriented PET sheet can be thermoformed to make packaging trays and blisters
- Its chemical inertness, together with other physical properties, has made it particularly suitable for food packaging applications
- Other packaging applications include rigid cosmetic jars, microwavable containers, transparent films, etc.

Check out food contact-approved PETs for various end-applications here.

PET monofilament is mainly used for making mesh fabrics for screen-printing, filter for oil and sand filtration, bracing wires for agricultural applications (greenhouses etc.), woven/knitting belt, filter cloth, and other such industrial applications.

High-end Engineering Applications Used Improved PET Grades

Thanks to good electrical insulating properties, high structural and dimensional stability, polyethylene terephthalate is widely used in electrical and electronics industry. It is an effective polymer to replace die casts metals and thermosets

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in applications like: electrical encapsulation, solenoids, smart meters, photovoltaic parts, solar junction boxes, etc. Polymer's outstanding flow characteristics enable design freedom and miniaturization to produce high-performance parts.

PET is successfully being used in many applications in the automotive industry. It is currently being employed in the following applications: wiper arm and gear housings, headlamp retainer, engine cover, connector housings.

In the automotive applications, reinforced PET can be more suitable than reinforced PP. This is because the standard requirement for usage temperature for an automotive component is -40°C to +80°C, which is difficult to fulfil with reinforced PP for semi-structural components like body panels.

Polyester Fibers in Textile Industry

PET has wide applications in textile industry. PET polyester fabrics are manufactured using melt-spinning. In this technique, molten polymer is extruded through narrow channels to form fibres.

High modulus low shrinkage (HMLS)	3.3	14.9
High tenacity (HT)	5.2	14.0
Low shrinkage (LS)	1.6	11.6
Super low shrinkage (SLS)	0.7	12.2

Shrinkage and initial modulus of different industrial PET fibers

PET are strong, flexible, and offer additional benefit of less wrinkles and shrinkage over cotton. Polyester fabrics are light-weight, reduced-wind, drag-resistant and more resistant to tears.

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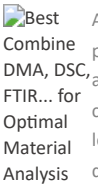
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